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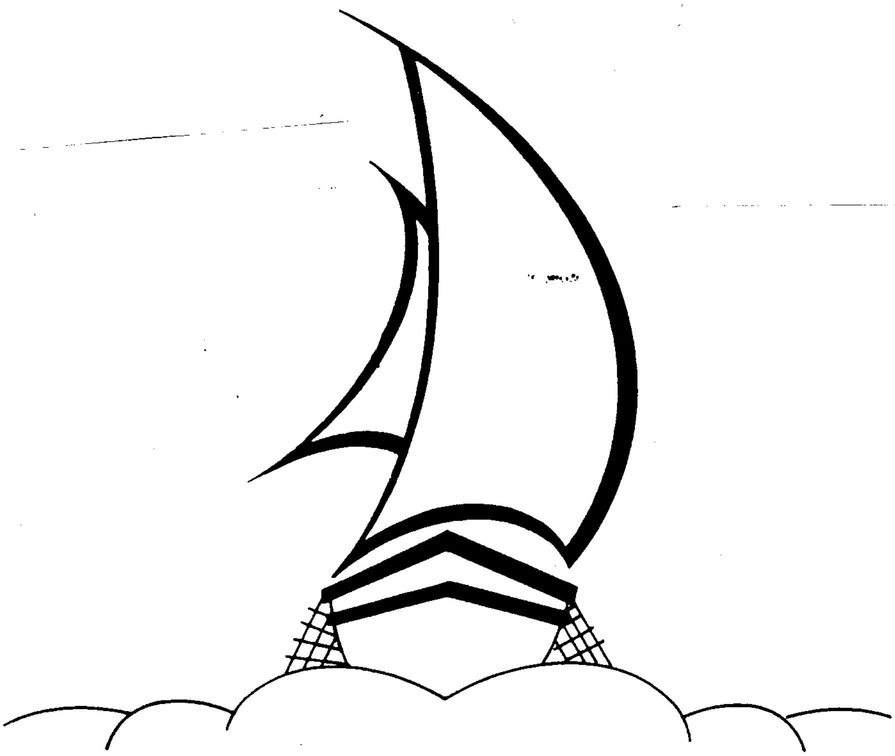

International Conference on Sail-Assisted Commercial Fishing Vessels: Proceedings Volume II

John W. Shortall III

FLORIDA SEA GRANT COLLEGE OCTOBER 1983

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INTERNATIONAL CONFERENCE

ON

SAIL-ASSISTED COMMERCIAL FISHING VESSELS

VOLUME II

Addendum to Proceedings of a Conference
Held May 15-18, 1983
at Tarpon Springs, Florida

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FOREWORD

This publication is Volume II of the Proceedings of the International Conference on Sail-Assisted Commercial Fishing Vessels. Twenty-two of the papers were pre-published in 458 pages of Volume I which was available for the participants at the Conference. The Table of Contents of the volume is reproduced herein.

There were 162 registrants from 14 countries at the conference. That, plus the number and generally high quality of papers given attest to the interest in this field. The first paper is an attempt by this Editor to summarize the results of that Conference.

It is important to note that registrants were asked to vote for the best papers. First place went overwhelmingly to: "Investigations into the University of Southampton - an outstanding piece of research. There was a three way tie for second place: "Some Aspects of Sail Power Applications in the German Sea Fishery," by K. Lange and P. Schenzle; "Linearised Performance Analysis of Sailing and Motor Sailing Vessels," by C.J. Satchwell and J. Mays; and "Retrofit Sail-Assist on New England Fishing Vessels," by C.A. Goudey and M.M. Linskey. Vote for best student paper went to a team of student researchers at the University of South Florida, College of Engineering: "A Windmill Thruster Experiment," by J. Dunlap, D. Luke, J. Nickelsen and T. Watts. The latter paper is reproduced in Volume II. All five were sent to The Society of Naval Architects and Marine Engineers (SNAME) for consideration for republication in that organization's journals and were voted best papers of the year from SNAME's Southeast Section.

Perhaps the most exciting development of the Conference was the presentation of full scale, experimental motor sailing performance data and the analytical approach developed by Satchwell and Mays for predicting such. There is at least sound data from France, Germany, England and the U.S. with which to check such analytical performance prediction schemes. More data will be forthcoming shortly and particularly from Norway. It is sincerely hoped that someone or ones will attempt to implement the Satchwell-Mays approach and check it against these data.

In an otherwise excellent conference, only one thing bothered me as conference organizer and prompts the insertion of a disclaimer here. On at least two occasions, my sponsors or I were cited as supporting or endorsing the work of others. Neither I personally nor either of the institutions which have sponsored my work (Florida Sea Grant College and University of South Florida College of Engineering) endorse any sail-assist program, certify any economics of others or are involved in any other sail-assist venture at this time. If this changes, it will be suitably published.

Readers will note that certain papers are reproduced that were not given orally at the conference. These include: notes from the November, 1982 Sausalito Sail-Assist Workshop, thanks to the courtesy of Chris Dewees and the University of California Sea Grant Advisory Program, a review by C.A. Goudey of my paper, recent advances by the Japanese as presented in writing, a note from K. Morisseau on North Atlantic winds, a short addendum by Dick Newick, a major paper by Frank MacLear and elaboration of a refrigeratin scheme by Capt. Kinsey. John Lord and Lloyd Bergeson gave certain written information which is also produced here in lieu of a formal conference paper.

My thanks to the Conference Sponsors, to the wonderful authors, presenters and moderators, to my steering committee, to my windmill engineers who to my sadness have now graduated, to the many helpers during the conference including: Kathy Hill and Julie Glover of SAILA, Linda Roman, Sherri Elwin, David Luke and Tom Watts of the University of South Florida College of Engineering, Ann Sainsbury of Florida Institute of Technology, Frank Raczkiewicz, Michelle Collet and Irma Rubin of USF Media Relations, and Billie Lowry and Tom Leahy of Florida Sea Grant College Communications and Publications. My thanks also to Barry Duckworth and Ken Diffenderfer for shooting TV footage of all of the conference. Above all, my thanks to my wife Carole for her help during the conference and the months before and after same plus her moral support.

John W. Shortall III
Conference Organizer
Tarpon Springs, Florida
September, 1983

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WORLD TRENDS IN SAIL-ASSISTED COMMERCIAL FISHING VESSELS

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ABSTRACT

There has been considerable difficulty on the part of many in accepting sail-assist as a practical energy and cost saver for large vessels, and there has been much contention among the "believers" over what kind of vessel and what kind of wind thruster should be employed. However, the case for wind assist for most commercial fishing vessels and for most fisheries now seems to have been firmly established for both new designs and the retrofit with sail rigs of older motorized craft. At the May, 1983 International Conference on Sail-Assisted Commercial Fishing Vessels, there were 31 presented papers and two panel discussions on this topic, and participants came from 14 countries. This paper attempts to summarize the key elements from that conference.

Described here are full-scale tests conducted in France, Germany, Norway, England and the U.S.A. and comparative computer projections. Modern designs for other countries are also outlined: west coast of Africa, Sri Lanka, Bay of Bengal and Brazil. The case for the catamaran workboat configuration is discussed with examples from work done in Australia, England, France, the U.S.A. and Third World countries. French tests of a single hulled vessel found that sails provided from 15 to 32% fuel savings. An aluminum catamaran fishing vessel saved one quarter of her fuel bill due to the lower resistance of the twin-hulled boat. The sails saved an additional 23%. Extensive experiments with a North Sea trawler gave fuel savings of 23 to 34%. A British experiment with a 15 ton 12.6 m (41 ft.) yacht projects fuel savings from 20 to 30% depending on service speed. The American NORFOLK REBEL showed savings ranging from two to 42%. Computer-aided projections for U.S. fisheries indicate potential savings of 15 to 40% depending on the specifics of the particular fishery and sail useage.

The data from full scale experiments and from studies seems to justify fully the retrofit of many older motorized fishing vessels with sails for auxiliary propulsion. It now seems time for private industry to design and market simple, inexpensive, easy to operate rigs for such.

Major gaps still exist in our lack of experimental data on advanced thrusters as wing sails and Magnus effect cylinders which offer the possibility of highly increased thrust per

square foot of sail area. Another gap is the comparison of the analytical tools advanced to predict motorsailing performance with full scale test data and modification of the methods to develop reliable prediction schemes.

INTRODUCTION

At this time, it is estimated that there are approximately 100 sail-assisted fishing vessels in the United States, at least half of which operate out of the West Coast in mid-Pacific or Alaskan waters. Accurate figures are not available on fuel savings, but the owners and operators appear satisfied with the monies saved. Some side benefits of sail-assist are:

A. More stable work platform, hence less fatigue, more safety and higher productivity.

B. Sails eliminate the need for towing insurance.

C. Ability to maintain speed longer in storm conditions before heaving to.

D. Although not yet proven, it seems reasonable that catch potential will be increased, since sail-assisted boats are relatively quiet.

It should be emphasized that most or all wind-assist designs are based on the premise of motor-sailing, i.e., operating the vessel with engine turning at reduced rpm when sails are up to maintain a constant ship service speed. A major problem for naval architects has been to predict motor sailing performance. There are reasonably accurate methods to predict performance under engine alone or under sails alone. Predicting the combined performance is not at all straightforward. Reference (1) is a landmark paper in this area which was followed by Reference (2) - another major step forward. Neither has yet been implemented in a practical way or tested against known experimental data insofar as is known by this author.

The importance of searching for fuel economy in the fishing industry may be highlighted by a few figures. The percentage of overall operating costs for fuel alone are listed beside each of three major fisheries as of 1982:

A. Stone crab-lobster Florida Keys Fishery: 15-20%.

B. Snapper-Grouper - Gulf of Mexico Fishery: 30%

C. Shrimp - Gulf of Mexico Fishery: 40-54%.

Shrimpers are notoriously poorly designed for today's high fuel prices. Only 1.0 to 1.7 pounds of shrimp are harvested for every gallon of fuel, and annual fuel costs for large shrimpers have risen from $10,000 to $12,000 to $80,000 to $100,000. Shrimp is the most valuable seafood crop landed in the U.S., and the Gulf of Mexico produces 80% of the dollar value in the U.S.A. (3) (4)

There are probably a few hundred thousand motorized commercial fishing vessels in the U.S.A., of which some 25,000 are registered in Florida alone. It is a relatively easy task for the naval architect to design new vessels which are optimized for the present-day fuel cost situation. It is not so easy to design a workable sail rig for an existing vessel - the retrofit case. These older fishing vessels, some still being manufactured from old, fuel-hungry designs, cannot be summarily dismissed. Thus, a few studies have indicated some retrofit rig possibilities, (3) (5) and one case has been full scale tested. (6) For new designs, Reference (7) may be consulted for an exhaustive compendium of ideas. This is a report prepared for The Society of Naval Architects and Marine Engineers Technical and Research Panel MS-11 on Fishing Systems. See also Reference (8). In addition, the use of advanced high modulus materials may be considered to reduce weight - a primary energy absorber. However, composites may be too fragile for the workboat environment.

In the retrofit case, the main objective is to reduce operating costs which translates into reducing engine rpm. One author has pointed out that operating diesel engines at low rpm can lead to increased engine maintenance from carbon buildup, increased oil change intervals and reduction in time between overhauls. (9)

References (7), (8), (9) and (10) imply a need to take a systems approach in the design of fishing vessels and investigate every area in which these craft expend energy, not just the obvious ones of weight, and hull shape and propulsion. This is the main thrust of the Japanese research effort in their energy economies for tankers and cargo ships which also included sail assist. (10)

The catamaran twin hull configuration has not seriously been considered for fishing boats in the developed countries until quite recently. (11) (12) The French began a series of trials of two full-scale prototype catamarans for coastal fishing in 1981 equipped with auxiliary sails. (13) Both paper studies and the French results indicate that this is a potentially very efficient fishing platform system. A major difficulty is public acceptance of an unusual design leading to possible resale difficulties.

With diesel fuel reaching $3.00 to $3.50 per gallon in some Pacific Islands and other countries, wind assist is a practical answer to effect a measure of fuel and cost economy. A number of papers treat this topic in various countries.

Coventional, soft yacht sails are not the only possible answer to wind auxiliary propulsion. Windmill rigs have the potential to propel vehicles directly upwind and are the subject of several investigations. Rotors of various kinds, such as the Flettner, are also being tested. They have a theoretical possiblility of ten to 12 times the thrust per unit area on many headings as compared to soft sails.

Participants at the May, 1983 International Conference on Sail-Assisted Commercial Fishing Vessels voted on the best papers of the 31 presented. First place went to Reference (14) which introduced new experimental methods and new numbers into the measurement of sail coefficients and in quantifying wind behavior on all sides of a sail. There was a three-way tie for second place: References (2), (5) and (6) - all outstanding papers. Best student paper award went to the authors of Reference (15). All five papers were sent to SNAME Headquarters for consideration for possible publication in "Journal of Ship Research" or "Marine Technology."

FULL SCALE TESTS - SUMMARY

Table one gives a summary of seven full scale sailing fishing vessel experiments conducted in the Federal Republic of Germany, France, U.S.A, Norway and England. The Norwegian experiments have not yet been completed at the time of this writing. Of these vessels, all were designed for auxiliary sail except for the German experiment which utilized an already retrofitted North Sea trawler type. The British CAMELEON is a ferrocement sailing yacht which was used to obtain motorsailing figures from which fuel saving projections were made.

Both the French and the operators of the NORFOLK REBEL made a very interesting and significant observation. Both felt, independently, that much greater savings would have accrued had the sails been used more frequently and had they been trimmed more efficiently. Commercial fishing is bone-tiring hard work. It may be too much to expect working fishermen to hoist sail whenever the wind is right, take down and bag or furl sail when it is not and reef in high winds on top of all their other arduous duties. Perhaps naval architects should rather be thinking of some easily controlled, fixed installation wind thrusters such as rotors, hard wingsails or windmills. Rotors are particularly attractive, since they would interfere very little with the fishing operation itself and leave a small "footprint" on deck.

The author of this paper's own limited experience on a commercial fishing vessel with sails is that proper sail trim is never achieved.

Table 1

FULL SCALE SAILING FISHING VESSEL EXPERIMENTS

	VESSEL	DATE	LOAD	DISPLACEMENT (Tons)	ENGINE HORSEPOWER	SAIL AREA	FUEL SAVINGS
A.	KFK FREDDY (Fed. Rep. Ger.)	1980-82	24.1 m (79 ft.)	131-179	195 (cruising)	180 sq. m. (1937 sq. ft.)	23-34%
B.	DARMAD (1) (France)	1981	11.6 m (38 ft.)	6.5 - 9	2 x 25	57 sq. m. (613 sq. ft.)	23%
C.	VER LUISANT (1) (France)	1981	9.0 m (30 ft.)	3 - 5	2 x 25	30 sq. m. (323 sq. ft.)	--
D.	CADOUDAL (France)	1982	20.5 m (67 ft.)	62 - 95	185	236 sq. m. (2540 sq. ft.)	15-32%
E.	NORFOLK REBEL (U.S.A.) (2)	1982-83	15.7 m (51.6 ft.)	33 - 42	320	104 -159 sq. m (1123 - 1707 sq. ft.)	2 - 42%
F.	NEW DEAL 33 (Norway) (3)	1983	10 m (33 ft.)	7	30 - 40	47 sq. m (503 sq. ft.)	--
G.	CAMELEON (England) (4)	1983	12.6 m (41 ft.)	15	?	172 sq. m. (1851 sq. ft.)	20% at 7.1 knots 30% at 6.4 knots

NOTES:

(1) DARMAD and VER LUISANT are catamarans.

(2) NORFOLK REBEL is a combination vessel for: towing, salvage, freight, fishing, research, etc.

(3) Full scale tests are being completed in 1983.

(4) This is an Ibold design: Endurance 40 ferrocement yacht which was tested to determine motor sailing parameters and performance data to use in projections of fishing vessel motor sailing performance. Figures in the fuel savings column give two such projections showing the lower the vessel service speed, the more wind assist will help economize.

FULL SCALE TESTS - FEDERAL REPUBLIC OF GERMANY

An excellent series of tests was conducted from 1980 to 1982 in the Baltic Sea with a 24m (79 ft.) fishing trawler currently used as a sailing yacht. Runs were made under engine alone, under sails alone and in the motor sailing mode in winds varying from calms to 25 knots. Figure one is a profile view of the KFK FREDDY. Figure two gives the results of many trials where shaft horsepower is plotted against angle to the true wind without leeway taken into account and for four wind speeds (true) from 10 to 25 knots. In actual trials, fuel savings are calculated to be from 23 to 34% on a long term average. The higher figure is judged to be attainable with an improved sail rig. Tests indicated that the potential power of the sails was at 50 to 72 sq. ft. per horsepower for average wind speeds of 15 and 12 knots respectively. For more modern sail rigs, the authors project 27 to 32 sq. ft. per horsepower for these two wind speeds. Figure three shows the required power at a constant ship service speed of nine knots with and without sails versus course angle to the true wind direction with true wind speed as the parameter. The average power reduction $-\Delta P$ - through use of sails is indicated. Computations included the integration of the time history of the wind in the Baltic and North Seas based on an equal probability of all course headings. (6)

FULL SCALE TESTS - FRANCE

Table one shows three French sail-assisted fishing vessels which were designed and built to optimize sail assist. They were operated in a series of demonstrations and tests in 1981 and 1982. A fourth is the schooner EOLE which was not reported on at this conference. The DAR MAD catamaran undertook cruises between successive fishing harbors, and volunteer fishing masters came aboard for trial expeditions to their fishing grounds. Their impressions were recorded on questionnaires. Cruises took place between September and November, 1981. Thirty-three ports were hailed, 140 masters were embarked and some 1500 to 2000 fishermen were involved. However, the dual goals of familiarizing fisherment with sail assist and taking measurements conflicted, and the VER LUISANT catamaran will only be used for systematic measurement trials. A plot of DAR MAD's fuel consumption rate vs. shipspeed with various wind and engine combinations is shown in Figure 4 and a derived power diagram is given in Figure 5.

Tests of the single hull CADOUDAL are presently underway. Preliminary results are given in Figure 6. Due to the testing methods and inadequate use of sails, fuel savings of only 15%

were derived from sail utilization. Savings of 32% are forecast for better sail use and trim. Lessons learned from CADOUDAL can lead to the design of an improved vessel with 56% fuel savings compared to CADOUDAL or 70% as compared to a conventional motorized trawler of equal length, due both to wind assist and improved hull and propeller design.

The catamaran hull configuration itself leads to about a one-fourth fuel consumption as compared to a single hull equivalent vessel. Over and above that, a 23% fuel savings was experienced by the use of wind assist.

This paper concludes by stating that for a new sail-assist vessel it is difficult to evaluate separately the wind contribution from the total energy saved. It appears that a fuel saving of about 50% is readily possible in a single hull craft - about half due to hull modification and half due to the use of sails. (13)

FULL SCALE TESTS - U.S.A.

Although there are on the order of 100 sail-assisted commercial fishing vessels in the U.S.A., only one has been subjected to an intensive measurement campaign to quantify the benefits of wind assist: the combination vessel NORFOLK REBEL. She is primarily operated as a tug and salvage boat but does do some commercial fishing. Figure 7 shows a profile view of the gaff-rigged craft with some of her basic measurements. Figures 8 and 9 give fuel use rate vs. vessel speed with and without sails, from on-board measurements. The NORFOLK REBEL made 16 fishing trips between November, 1981 and November, 1982. Useful data resulted from seven of these trips and provided some 333 observations in three different types of fishing: bottom fishing, longlining and trolling. As with the French experience, the major limiting factor in fuel economy was the amount of sail utilization as the following table shows:

Table 2

NORFOLK REBEL FUEL SAVINGS AND SAIL UTILIZATION

Type Fishing	Duration (hours)	Overall% Sail use	Overall% Fuel Saved
A. Bottom Fishing	55-117	4-33%	3-18%
B. Long-lining	102-129	10%	2-6%
C. Trolling	8-9	45-83%	29-42%

The report gives a plot from these data of percent sail use vs. percent fuel savings which is essentially linear.

Average wind speeds during this study were 9.2 knots. For limited periods while bottom fishing, fuel savings of 50% were attained over a 15.7 hour run. On two other trips, 20% and 25% savings were realized. The authors of this paper comment on sail utilization: "The fishermen employed on the NORFOLK REBEL, both sailors and non-sailors alike, accepted the extra work involved in sail handling because of the reduction in fuel costs and the dampening of the rolling motion of the boat. However, during runs of just a few hours or less, the time needed to raise and lower all the sails was not always worth the effort, especially when there was a lot of gear work to be done on deck." Extra crew was not required because of the use of sails, and the learning process for non-sailors was fast. Sails improved safety and seaworthiness. They acted to steady the rolling and pitching motions of the vessel in a seaway, providing better footing on deck – thus eliminating the need for fuel-hungry paravanes. (16)

FULL SCALE TESTS – NORWAY

The Norwegian boatbuilding firm A.S. Morebas is in production on a series of 10 m (33 ft.) sail-assisted fiberglass fishing vessels. The Peter Norlin-designed boat is shown in Figure 10, and her particulars are given in Table 3:

Table 3

PARTICULARS OF THE NEW DEAL 33

LOA – 10.00 M (33 ft.)
Draft – 1.45 m (5 ft.)
Beam – 3.16 m (10 ft.)
Sail Area – 47 sq. m (503 sq. ft.)
Displacement – 7 tons

The sail rig consists of a large furling genoa plus a small mizzen hanging off the stern – a steadying sail. At the time of this report, tests had been completed by the manufacturer for the engine-only case without sails up when equipped with a Perkins 40 hp diesel engine. At a displacement of 8.4 tons, a speed of 8.2 knots was obtained consuming 8.23 liters of fuel per hour. A cruising speed of 7.7 knots was attained consuming 5.85 liters per hour. Loaded to a displacement of 12 tons, at a speed of 8.0 knots, the fuel consumption rate was 9.41 liters per hour and at 7.6 knots, 6.0 liters per hour. Conventional Norwegian fishing vessels of similar size and displacements normally have engine installations of 80 to 120 hp consuming 15 – 25 liters per hour (4.0 – 6.6 U.S. gallons) to obtain speeds of about 8 knots. One production vessel has had a 30 hp Norwegian Saab diesel engine installed. This is currently being operated by Dr. Arnt Amble of the Nordland Research Institute for fuel utilization tests using on-board microcomputer-interfaced instrumentation.

FULL SCALE TESTS - ENGLAND

These were not reported at the International Conference, but due to their timeliness and appropriateness, results are included here, as this represents another source of experimental data on motor sailing. An exhaustive series of tests was recently completed on a ferrocement, Peter Ibold-designed Endurance 40 type yacht rigged with the Gallant sailing rig - the Aerosystems Wingsail invented and patented by Jack Manners-Spencer. This symmetrical, soft wingsail is discussed later and is described in detail in Reference (18). Particulars of the vessel used in these tests are given in Table 4:

Table 4

PARTICULARS OF THE YACHT CAMELEON

LOA - 12.6 m (41.3 ft.)
LWL - 9.7m (31.8 ft.)
Beam - 9.7 m (31.8 ft.)
Displacement - 15 tons
Draft - 1.8 m (5.9 ft.)
Ballast - 4.5 tons
Sail Area - 172 sq. m (1851 sq.ft.)

Figures 11 and 12 show a profile view/sail plan and give a rig description. Figure 13 illustrates results of a wind tunnel test on a 1.86 sq.m (20 sq. ft.) model of the Gallant rig. (18) Motor sailing tests were conducted in February, 1983. The following six parameters were continuously measured and recorded: torque, engine rpm, ship speed, wind speed, wind direction, heel angle. As with other full scale tests, runs were first made under engine alone in wind speeds of Force 2 and 5 (4-6 and 17-21 knots) with the wind on the bow and the quarter. The motor sailing trials were conducted at a variety of wind speeds and shaft rpms at course angles to the true wind ranging from 60 to 180 degrees. Performance under sail alone was also measured. Although the exact sail area when double-reefed is not known, an extimate can be made of the sail efficiency at 50 to 60 square feet (4.6 - 5.6 sq. m) per horsepower in 20 knots of true wind at a course angle of 140 degrees to the true wind direction.

The author of this report argues very effectively that it is not possible to say that a fishing vessel fitted with auxiliary sail will save a certain percentage of fuel compared to a vessel without sail. "This is because there is a very large number of ways in which the power driven vessel can be operated, depending entirely on the demands which the skipper puts on the vessel." He cites several examples:

A. Engine set to predetermined rpm and vessel speed varies.

B. Adjust engine rpm for constant service speed.

C. Engine speed adjusted to suit the urgency of the situation, i.e. to reach a market on time or to reach port on a favorable tide or tidal level.

Making some reasonable assumptions, based on these tests, the author concludes that overall fuel savings would be about 22% for a service speed of 7.1 knots($V/\sqrt{L}$ = 1.26) and about 30% at 6.4 to 6.5 knots ($V/\sqrt{L}$ = 1.14).

Maneuvering trials were conducted to simulate gear recovery in winds of Force 6 to 7 (22 - 33 knots). Under engine only and while motorsailing there were no problems in picking up the moored test buoy. Under sail alone, it took three attempts, and there was difficulty in hauling the gear.

The author also discusses vessel behavior. First thing noticed was freedom from roll under sail. Even under engine only, the keel helped damp out roll. No flogging of sails was experienced when luffing up the Gallant rig even in winds up to Force 7. Jibing was quite easy as were raising, lowering and reefing the wingsails - very important on a commercial vessel. The rig was easily handled by a small crew. Masts were freestanding and of tapered fiberglass with varying wall thickness. A redesign of this craft is shown for commercial fishing operations. Use of a controllable pitch, fully feathering propeller is urged. (19)

OTHER MOTOR SAILING EXPERIMENTS

A study has recently begun and initial results reported by researchers at the Florida Institute of Technology in Melbourne, Florida using a 7.6 m (25 ft.) LOA Fisher design Fairways Potter 25 as is commonly used in crab and lobster pot fishing in Europe. RPM, vessel speed, wind velocity and wind angle are recorded in these preliminary tests which began in April, 1983. Early results show rpm reduction varying from five to 29% at boat speeds of 5.0 to 6.6 knots. (20)

Instrumentation and computer-aided on-board data acquisition and analysis techniques are being assembled and developed at the University of South Florida College of Engineering with the support of Florida Sea Grant College. It is intended that the following parameters will be measured on conventional and sail-assisted fishing vessels: ship speed through the water, leeway angle, apparent wind angle, apparent wind speed, engine rpm, fuel flow rate and time history, engine torque, stability monitoring (GM), air and water temperatures, sail use history, hull fouling history and heel angle. It has not yet been firmly decided whether to conduct a full scale experiment using this package - a suitable vessel and crew have yet to be located. This may be accomplished in 1984. (21)

COMPUTER-AIDED AND OTHER DESIGN STUDIES - THE RETROFIT CASE

The almost-three year old program conducted with the support of Florida Sea Grant College at the University of South Florida College of Engineering has been amply described elsewhere. (3) (21) (22) It was recognized early on that the application of sails must be studied on a fishery by fishery basis, and that has been done in several cases for fisheries of importance in this region. Investigations always commence with a gathering of information on the specific fishery to include typical routes for calculation of wind probabilities and for information to feed into a 15 year life cycle engineering economics computer program to determine whether it is feasible to consider sail assist in this specific fishery. Stability estimates are then made and conceptual sketches drawn of various possible sail rigs with consideration given to the aero/hydrodynamics, stability and structure of the vessel and the need to leave deck space clear for the fishing operations. In most cases, the freestanding mast seems attractive using conventional soft sails. Speed estimates are next made combined with analyses of wind statistical data (direction and strength as a function of month of year) and the particular fishing routes traversed by the fish boats being studied. Conclusions were that fuel savings of between 15 and 40% were possible depending on the fishery and assuming sail use only going to and from the fishing grounds. More enterprising fishermen would find ways to increase sail utilization. These figures seem reasonably in accord with the recent full scale results published in References (6), (13), (16), (19) and (20). All cases studied were for the retrofit of existing craft. Two preliminary designs are now being developed for newly built vessels.

A very thorough design study for the retrofit of the VINCIE N. was prepared by the authors of Reference (5) which also shows sail rig retrofit designs for trawlers of lengths 16.8 and 17.7m (55 and 58 ft.). The VINCIE N.is a 26.2 m (86 ft.) New England side trawler whose profile and designed sail rig are shown in Figure 14. The thoroughness of this design study is illustrated by the taking of resistance data from towing the vessel with the cooperation of the U. S. Coast Guard. The authors present a very convincing argument for limiting the sail area on retrofit rigs as illustrated in Figure 15. They state that the sail plan size and level ofcomplexity should maximize the owner's return on investment.

"... we assume that the vessel is presently an attractive fishing platform and any significant deviations from the present methods of gear handling may represent an unacceptable economic risk to the owner." They continue that the dollar benefits from reduced motion in a seaway are hard to quantify and that the improved propulsion coefficient (when using sails plus engine) does not lend itself to analysis and is not easily isolated from sail thrust during sea trials. "It is suspected that much of the unexplainable synergistic effects of motor sailing could be accounted for by the the improved propeller efficiency." "The costs and benefits of a sail-assist installation are very boat specific...Figure 15 is a hypothetical example of what a cost/benefit analysis might reveal." An optimum-sized sail plan can result which is far different than might be expected based on conventional sail boat proportions." (5) Sadly, it now appears that due to legal complications not associated with this project, the VINCIE N. will not be retrofitted.

OTHER SAIL-ASSISTED FISHING VESSELS

Reported on briefly at the International Conference was the 11.4 m (37.5 ft.), 2.9 ton fish hold capacity, 68 sq.m (734 sq.ft.) sail area AQUARIAN 38 sailing fishing vessel now in production by Thompson Trawlers in Florida. As far as is known, there is no intention of conducting instrumented trials. One such craft is fishing in the near-Atlantic, Southeast U.S. waters. (37)

CATAMARAN COMMERCIAL FISHING VESSELS

A major problem for naval architects designing vessels for many parts of the world is the need for shoal draft - one meter (3.3 ft.) or less. This is certainly true in the author's region: Florida and the Gulf of Mexico. Catamarans have undeniable appeal from that point of view. Some of their advantages and disadvantages as fishing work boats are summarized in Table 5: (3)(11)

Table 5

ADVANTAGES AND DISADVANTAGES OF CATAMARAN WORK BOATS

PRO	CON
A. Shoal Draft.	A. More stable upside down.
B. Beachable for offloading, bottom cleaning and maint- enance.	B. Motion in a sea not always pleasant.

C. Low wave resistance.	C. Sail rig must be overdesigned due to lack of heel.
D. Up to 50% of cargo may be considered as ballast.	D.Lack of consumer acceptance. leading to probable poor resale possibilities.
E. Stable, non-heeling platform.	E. Arguable whether safe for any but coastal fisheries.

F. Large deck/work space.

G. Size of trawl doors may be lessened due to catamaran beam.

H. High payload to displacement ratio.

In addition, the author of Reference (24) claims that the fishing catamarans he has designed are safer in surf operations - launching and recovery - than their single hull equivalents. His SANDPIPER design was first developed for commercial fishing in Ghana. A modified version used now in Sri Lanka is shown in Figure 16. (25)

The Australian yacht designer Lock Crowther has launched two aluminum commercial catamarans. The 22.4 m (73.5 ft.) DMB is illustrated and described in Figure 17. "She sails comfortably at 9 - 13 knots and easily reaches a speed of 18 knots under reefed mainsail alone in 34 knots of wind . . . Even in light winds the average speed is high. We had 11 knots on thelog in 8 knots of true wind." Another catamaran workboat design by Crowther is a 14.0 m (46 ft.) aluminum trawler/game fishing catamaran which has twin masts, side by side, and is of the mast aft type. "For large boats (13.7 , - 45 ft. on up) aluminum has proven the quickest, cheapest, lightweight form of construction available." (12)

Sylvestre Langevin, the noted designer of ELF ACQUITAINE, is also the designer of some of the French commercial sailing fishing catamarans. He presented a paper on the characteristics of multihulls in sea conditions and cites his experience on a 22 m (72 ft.) long catamaran where, after five days at sea, the bridge deck longitudinals became completely dislocated by wave pounding on the the underdeck and began to separate from the hulls. He attrributes many of the seagoing structural problems of catamarans to excessive pitching monent. He discusses possible remedies such as increasing the damping through use of a hard chine or a step near the waterline or reducing the moment of inertia by concentrating weights at the axis of rotation. "The axis of rotation in pitch is, for all catamarans studied up until now, approximately an axis containing the center of gravity of the waterline surface." (longitudinal center of flotation). He also mentions the possibility of decreasing the lift of the after portion of the hull by fining the lines there slightly, or through use of a damping foil.

Langevin maintains that a working catamaran with furling jib likely will not sail beyond 70 to 75 degrees from the true wind direction with a leeway of five to seven degrees, as taken from tests with DAR MAD. However, if one of the engines is run at one-quarter speed, leeway is almost completely eliminated. He feels that trimarans have much better upwind performance than catamarans. "...the lateral stability (of catamarans) increases the deck load." He has examined the problems of the need to overdesign the sail rig and has come up with these figures: "Comparing identical sail areas on a catamaran and a single hull craft, the supplementary load carried by the catamaran rigging leads to an increase of 25 to 30% for the mast moments of inertia and for the strengths of the standing and running rigging components. Sail material strength must be increased by 15 to 20%." He examines the case for the wing sail and finds its only drawbacks are cost and complexity. he is working on the Chapouteau sail - a soft,variable camber wingsail. (23)

Dick Newick's 9.75 (32 ft.) one ton cargo capacity trimaran sailing pickup truck for developing countries is shown in Figure 18. She was built in about 1500 manhours using the Constant Camber (R) technique. She has been rigged for bottom, trawling, trolling, trap and hook and line fishing trials off Guyana in South America. (26)

As indicated previously, fuel prices in the Pacific are very high. This enormous area - the Pacific Basin is much larger than the United States - is sprinkled with islands whose entire economies ar based on service by sea. One author described this situation and presented the design of a simply-built catamaran 21.5 (41 ft.) long by 7.92 m (26 ft.) beam overall specifically designed for deep sea fishing and to be manned by Pacific islanders. (36)

SAIL-ASSISTED FISH BOATS IN DEVELOPING COUNTRIES

E.W.H. Gifford and C. J. Gifford, joint directors of Catfish Ltd., have designed sailing fish boats for a number of countries including: Sri Lanka, South India and West Africa. Their work was cited earlier in the discussion of catamaran work boats. They also have done a number of rig experiments using sprit, lug and lateen sails fitted to their double-hulled surf beach fishing boats. They conclude that the lateen rig, improved version, appears most suitable for small boats in tropical wind systems. (25)

The firm of MacAlister Elliott and Partners, Ltd. has been working closely with the UN Food and Agriculture Organization - FAO - on small-scale sail-assisted fishing vessels. "Small-scale artisanal fisheries of the developing countries produce at least one-third of the annual world seafood catch of some 55 million tons. Between 20 and 30 million artisanal fishermen . . . depend on small-scale fisheries for their livelihood." Some sample diesel fuel prices in areas of concern: Somalia - $2.20 per gallon, Guinea Bissau - $3.47, Sierra Leone - $2.70, Senegal - $1.20 (representing 40% of operating costs). These countries have per capita earnings of $160 to $223. Figure 19 shows some results of fuel consumption trials on an 8.7 m (28.5 ft.) inshore fishing craft with a 30 BHP engine. 24 sq.m (250 sq.ft.) of sail was installed. At 90 degrees to the apparent wind direction in a true wind strength of 15 knots, fuel useage was 1.25 liters per hour as opposed to 3.8 liters per hour under engine alone at a ship speed of 6.5 knots - a fuel savings of 67%. At 50 degrees to the apparent wind, fuel consumption was 2.4 liters per hour - a 37% savings. "...the most significant contribution of appropriate, locally produced sailing rigs is in the context of motor sailing, where reductions in engine hours up to 50% have been recorded whilst maintaining previous levels of fishing achievement." In developement projects, the following rigs have been experimented with and used: gaff, sprit, Chinese lug, dipping lug, standing lug, gunter and lateen. Figures 20 to 23 illustrate some of these. (27)

A major effort is being made in Sri Lanka to develop small motor sailers on the order of 8.5 m (28 ft.) for local fisheries. Work is done with the support of FAO, USAID, the Netherlands government and the government of Sri Lanka. Boats are bult of fiberglass reinforced plastic, powered by 22 hp engines, fitted with unstayed masts and lugger rigs and can carry 4.5 tons each of fish in an insulated hold. Compared to the older 30 hp 8.5 meter motorized fish boats at full speed, the new boats consume 4 liters perhour as opposed to the older craft at 8 to 9 liters per hour - a fuel saving of 40 to 50%. When using sails and engine, a total fuel savings of 75% is achieved. (28)

Another major program has been undertaken in Brazil by the Pesca a Vela Project. Diesel fuel costs over $2.50 per gallon, and several of the larger Skookum sailing fishing boats are being purchased. Also being built in Brazil is a 10 meter (33 ft.) catamaran designed by John Marples. (29)

SAFETY AND STABILITY

"Fishing vessel casualty data for the years 1972 through 1979 show an ever increasing number of vessels lost and deaths on fishing boats due to foundering, flooding and capsizing. In 1978 and 1979, 144 people in the U. S. lost their lives in these three casualty categories, and 169 vessels were lost.

Fires, explosions, groundings, collisions and material failures contributed to the deaths of 22 in that period and 135 boats were lost from those causes. In 1980, the trend continued. Of 60 people killed on fishing vessels, 44 were lost from foundering, capsizing and flooding accidents." In the U.S.A., contrary to most other countries, fishing vessels are classified as "uninspected commercial vessels." There is a criterion for ocean going commercial sailing ships, and it is outlined together with five example ship specifications designed to this regulation. An 11.4 m (37.5 ft.) sail-assisted fishing vessel is studied with this rule and found to have "excellent ability to survive in extremis." (38)

INSTRUMENTATION

Instrumentation has been mentioned several times with respect to the full-scale experiments conducted or planned. An excellent paper was presented on microprocessor based on-board instrumentation for the operation of sailing commercial vessels. In particular, there is a very thorough discussion of sensors such as those used in measuring; torque, thrust, shaft rotation, fuel flow, vessel water speed, vessel land speed and values derived therefrom to enhance the profitability of a sail-assisted commercial fishing vessel. (39)

ADVANCED THRUSTERS

Conventional yacht sails are not the only way to extract energy from the wind and translate it into propulsive power. A fine paper was given by Dr. Blackford on his long term experiments with windmills as thrusters. His conclusions are that a windmill compares favorably to a wing sail at low speeds but not at high speeds in net propulsive force. See Figures 24 and 25. (30) The windmill is the only known wind thruster which can propel a vehicle directly upwind. This was amply demonstrated at the Conference by a windmill-propelled catamaran, 4.7 m (15.6 ft.) in length designed and built in 16 weeks by a team of students at the University of South Florida College of Engineering. (15)

Long of interest has been the Flettner or Magnus Rotor as a means of propulsion. Figure 26 is presented as a curve of lift (or sideforce) coefficient vs. ratio of the velocities of the rotor surface to the apparent wind. This ideal coefficient approaches 14 or 15 which means that theoretically it can have up to 12 times the thrust per unit area as a conventional sail. However, the problem is more complex than this, and there likely is a dependence on absolute wind velocity and what happens to the drag coefficient and the all-important lift to drag ratio as well. The usual Flettner rotor must be powered by a small engine. Figure 27 shows a possible self-starting Magnus Rotor, and it has been reported that the British are experimenting with another self-starting configuration — a rotor with an orifice (Coanda effect). Figure 28 illustrates three possible arrangements of Flettner rotors. "The major advantages of the Magnus rotor are; ease ofcontrol (speed and direction of the rotor is the total control requirement), high lift, the ability to reduce air draft by telescoping the rotors and simple cylindrical construction. The major disadvantage of a single or a fore-and-aft pair of rotors . . . is the lack of downwind performance." The author presents a chart in Figure 6 comparing various advanced thrusters on the basis of economics, minimum angle to the wind and personnel operators and maintainers. (31)

It has just been reported that Jacques Cousteau has launched his 20 m (65 ft.) MOULIN A VENT catamaran powered by an "aspirated cylinder," 13.5 m (44 ft.) high. The thruster is a non-rotating slotted cylinder 1.5 m (5 ft.) diameter with a full-length flap and a 12 hp fan at the top. "By the end of 1984, at least three private commercial ships will be at sea using cylinders."(44)

The wing sail, whether hard or soft, is appealing as a thruster. Wind tunnel tests on the Gallant rig were shown in Figure 13 and indicated a maximum lift coefficient of almost 1.2 and lift-to-drag ratio of 4.4 at that incidence angle.

The "Tunny Sail" is a variable camber, soft wingsail and is shown in Figures 29 and 30. It was invented by the Combewrights who crossed the Atlantic with this rig. Multiple sheets are used to control the asymmetric aerofoil. Another rig is being fitted to a fishing vessel. The battens shown in Figure 29 can be warped into an appropriate NASA GA (W) 1 cross section. (32)

The Walker wingsail is discussed by its inventor who criticizes the Flettner Rotor has having a poor lift to drag ratio. (33)

The hard wingsail as developed by the Windship Company and Lloyd Bergeson has attained lift coefficients of 2.0 in wind tunnel tests. (34) In a modified hard-soft wingsail, the Japanese have measured lift coefficient of 1.8. (35)

ANOTHER OPINION

The author of Reference (43) has strong opinions on sailing rigs for commercial vessels. He cites two of his recent cutter yacht designs: 25.2 m (86 ft.) ARIA II and 18.9 m (62 ft.) FALCON II. On ARIA II, one person can trim a 260 sq.m (2800 sq.ft.) genoa or a 335 sq.m (3600 sq.ft.) drifter. For commercial sail, he favors a stayed rig with every sail boomless, loose-footed and triangular with full luff support and luff roller furling on a grooved stay. It is the most reliable, the most maintenance free and requires the smallest

RIG	LIFT/$*	MINIMUM ANGLE TO WIND	MANNING OPERATORS NO.	MANNING MAINTAINERS NO./SKILL
SQUARE	9.9	45^o	VERY HIGH	HIGH/LOW
STAYED FORE & AFT	18.5	30^o	HIGH	HIGH/LOW
UNSTATED CAT	13.2	30^o	LOW	MOD/HIGH
DYNASHIP	21.1	40^o	LOW	HIGH/HIGH
SHIN AITOKU MARU	22.5	20^o	LOW	MOD/HIGH
AIRFOIL W/SIMPLE FLAP	34.5	15^o	LOW	MOD/HIGH
SLOTTED AIRFOIL	41.7	15^o	LOW	MOD/HIGH
WINDMILL	NA	0^o	LOW	MOD/MOD
ROTOR	109.9	20^o	LOW	MOD/HIGH

*C_L/($1000/$ft^2$)

Table 6: Rig Comparison Table. (2, 5, 6, 8, 9, 10, 11, 12, and 13)

The last four rigs in Table 6 are considered to be on the fringe of the current state of the art or beyond. Three out of four show a significant cost per unit of lift advantage. The fourth "rig" the windmill is not a lift device. The balance of this paper will focus on these high performance devices.

crew. "In the last 10 years and particularly the last two, great steps have been taken in simplifying sail handling. Today a 110 lb girl can set sails 10 times faster than five strong men could have done 10 years ago." He debates the freestanding vs. the stayed mast and comes out in favor of the latter but sees a place for the former in some applications. One problem with the freestanding mast is fatigue damage from lateral and longitudinal whipping. He dismisses wing sails mainly on the ground that they ignore the wind gradient - i.e. the change in wind velocity and apparent wind direction with height from sea level.(43)

DURABILITY OF DACRON SAILS

The author of Reference (45) has many years experience as a sailmaker and a sailor. "The heavier the fabric, the longer it is going to last. Today we are getting sails back in the loft that are 25 years old and have made a couple of trips around the world. After some resewing they are ready for many more years of use. Most of these sails are of 9 ounce or heavier dacron and sun damage has not occurred." He recommends against batten pockets or roach for work boat sails and for stronger and heavier corners than usual. "Seams should be broader than normal to provide width for double stitching later. The sails should be triple stitched initially and the two edge rows should be through both thicknesses of cloth. If possible, the dacron should be ordered with its natural woven selvage edge rather than the burned edge..." He recommends use of the softest dacron available - Bermuda cloth or softer - for ease of handling.

INVESTIGATIONS INTO 2D MAST/SAIL INTERACTION

While not entirely pertinent to this paper, the outstanding piece of research presented at this conference was the above-titled paper by Sturart Wilkinson of the University of Southampton. A variable camber airfoil was used in wind tunnel testing with an elaborate and precise mobile pressure sensing probe, remotely controlled, to move over the surface of the airfoil. Figure 31 gives a summary of the general results and Figure 32 shows some of the parameter ranges measured across a mainsail behind a mast. One of many plots of static pressure distribution is shown in Figure 33.

MAJOR GAPS IN KNOWLEDGE AND FUTURE PROSPECTS

The primary technical gaps are lack of experimental data on advanced thrusters as rotors and wing sails and our inability to predict motor sailing performance. As indicated earlier, the latter was well treated analytically in References (1) and (2), both of which represent outstanding work in this author's opinion. It is now time for these analyses to be implemented with computer programs to predict motor sailing performance and to compare these analyses against the experimental data published in the Proceedings of the Conference and from ongoing experiments. Much more motor sailing data should be available in 1983 and 1984 as several measurement projects continue. As in sailing yacht research, sadly lacking from these data are leeway angle measurements.

It is clear that wind assist is just one possible method to achieve operational economies in fishery operations. Aluminum or high modulus hull structures can help to keep weight down but suffer from the potential problems of possibly not being rugged enough to survive the workboat environment. Most fish boats have a payload to displacement ratio of 15% or so -not very good. The relatively light displacement, load-carrying catamaran may well have a place in some fisheries.

Of much more significance than the technical gaps is the human gap. So far largely unconvinced of the cost savings possible from wind assist are the fish boatbuilders and the commercial fishermen. Dinosaurs continue to be launched, but fishboats are sold in decreasing numbers. Who can afford them? Fish catches are declining, and the dockside sale price of fish has increased only gradually in recent years as the cost of living and fuel prices have exploded. The retrofit problem must be adressed with simple, inexpensive rigs to give a modicum of cost savings. We cannot discard all existing fishing boats, even the dinosaurs. New boatdesigns should be simple, lighweight, low costand certainly have wind assist. Of all the possible wind thrusters, the Flettner rotor and hard wingsails seem the most promising.

It is now time, in this author's opinion, for the yacht industry to manufacture and market retrofit rigs for older fishing vessels. The case for sail-assist has been well proven, and this "sideline" might well help level out some of the valleys in this cyclic industry.

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BIOGRAPHY

The author is a practising naval architect and at the University of South Florida College of Engineering teaches that subject plus computer aided design: CAD subjects such as CAD/Yacht Design, CAD/Structures, CAD/Stress Analysis, CAD/Machine Design, senior and graduate level Project Design and similar topics. He is a member of SNAME, Panel H13 of SNAME on sailing vessel and sailing yacht research and Chairman of the Southeast Section of SNAME for 1983-84. He is also a member of: Society of Small Craft Designers, Royal Institution of Naval Architects, American Society of Mechanical Engineers, IEEE Computer Society, Ocean Engineering Society, etc. He spent three years as an officer in the U.S. Maritime Service and Merchant Marine on ocean-going ships and four seasons on Great Lakes vessels. He has sailed small boats and yachts, both sail and power, since 1943.

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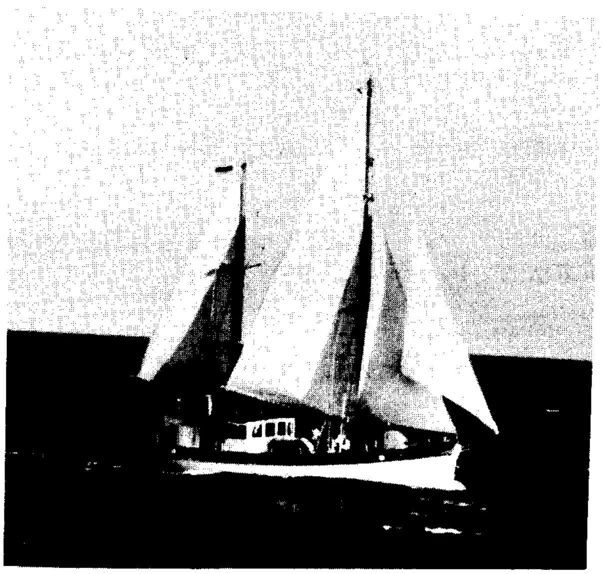


Fig. 1

KFK FREDDY

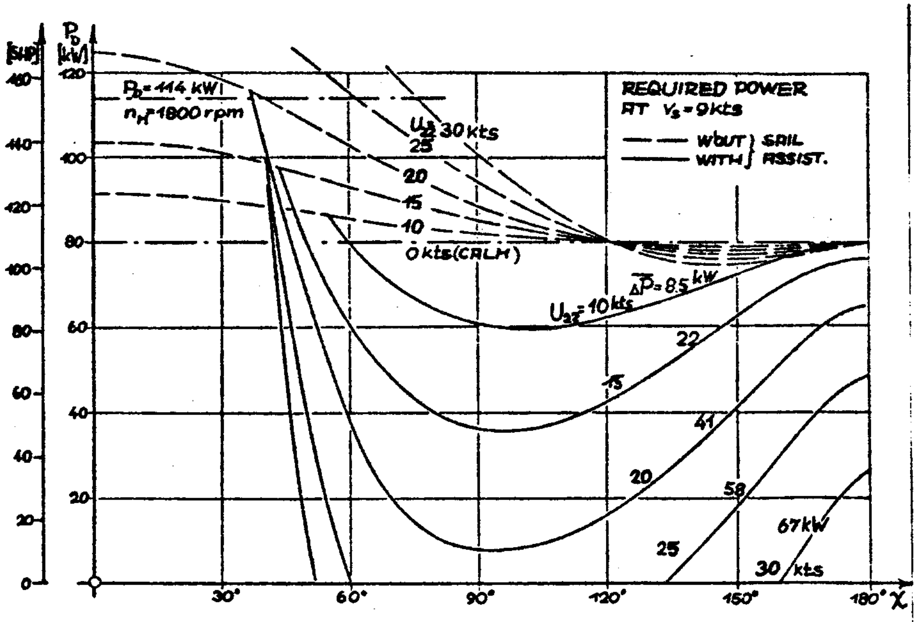


Fig. 2

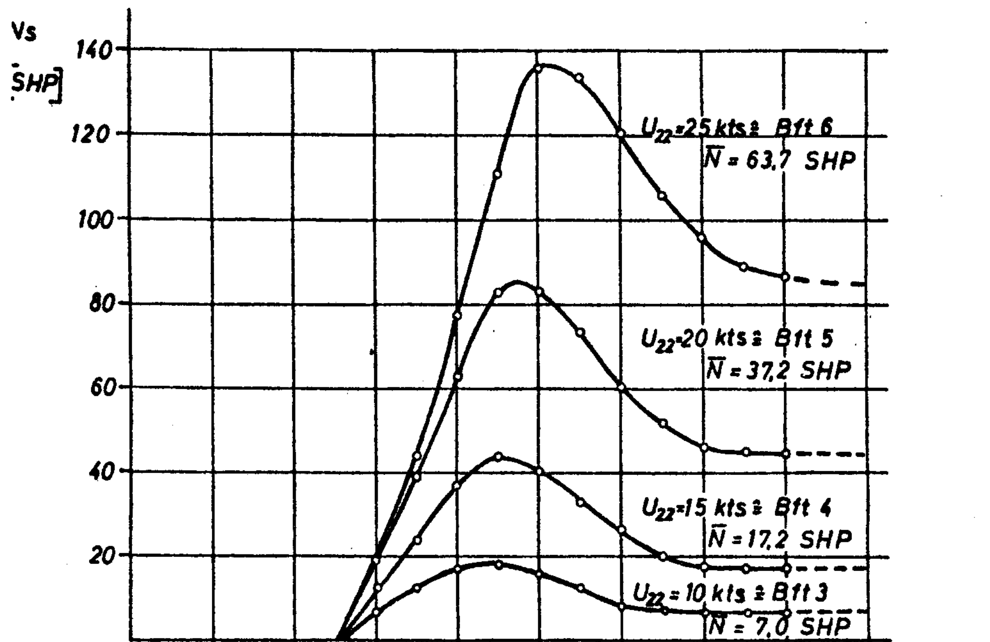
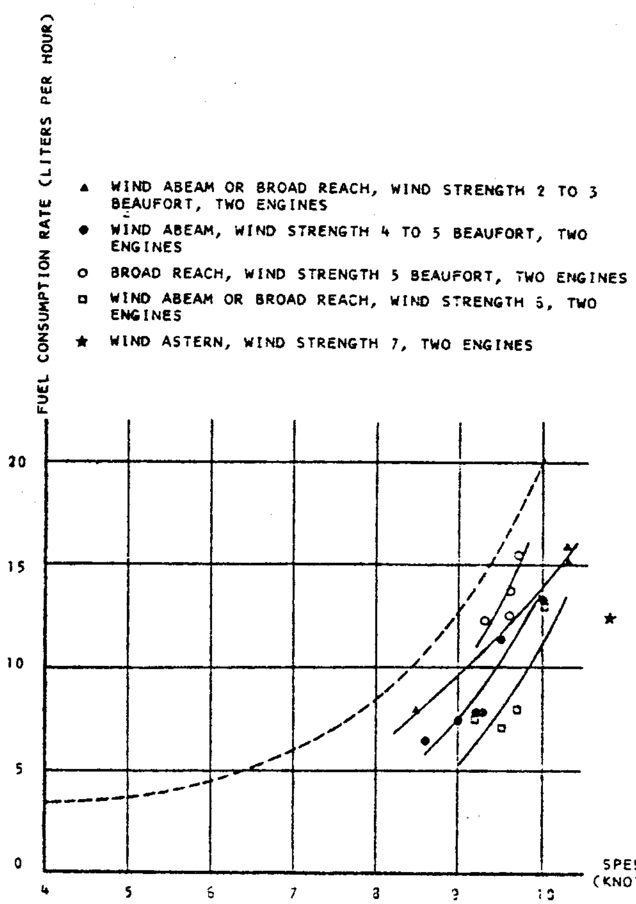
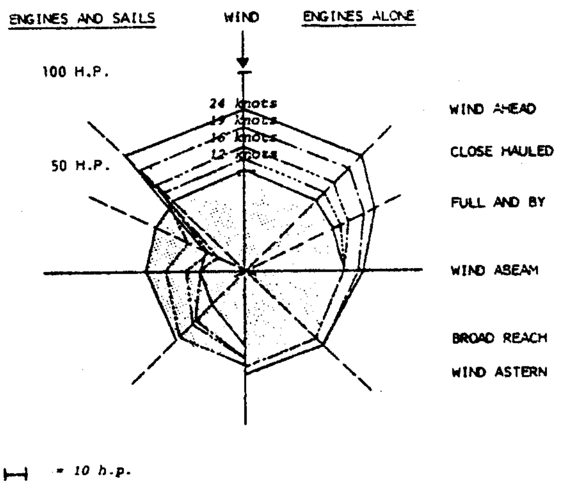


Fig.3



: "Dar Mad" - Fuel consumption rate versus ship speed, sails and engines, under various conditions (the dashed curve represents the variation of fuel consumption as a function of ship speed, engines alone)

Fig. 4



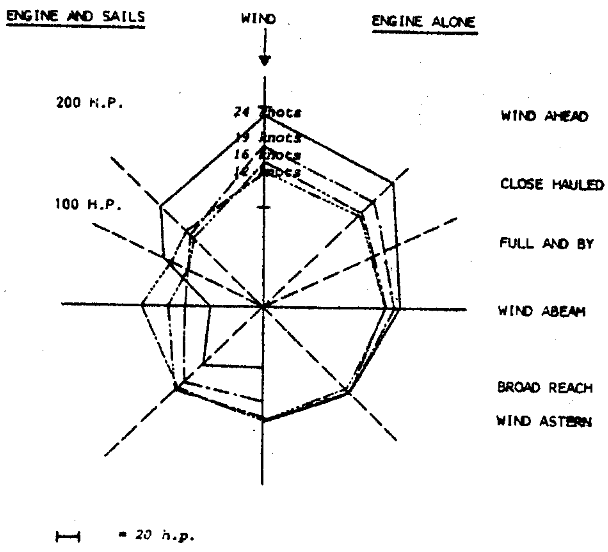
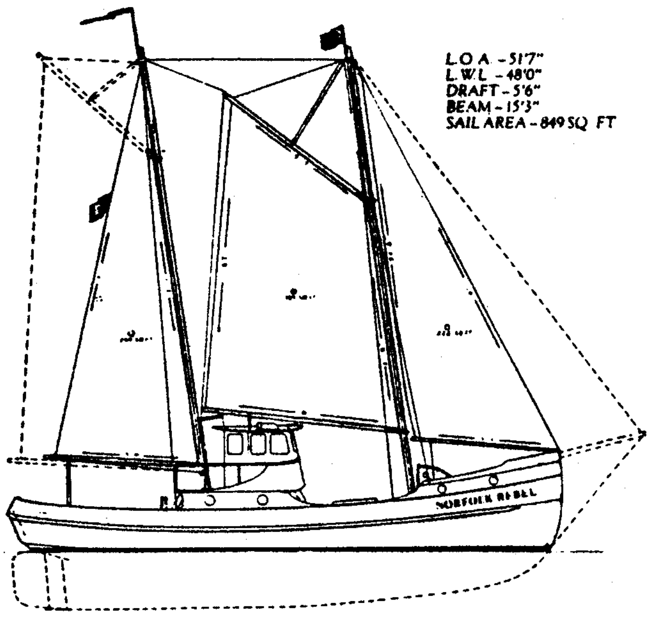


Fig.6 "Cadoudal" : power diagram

"Dar Mad" - Power diagram
(the shaded region corresponds to the use of one of the two engines only)

Fig. 5



TUGANTINE®
NORFOLK REBEL

Fig. 7

Figure 8 Fuel Use Rate vs Boat Speed

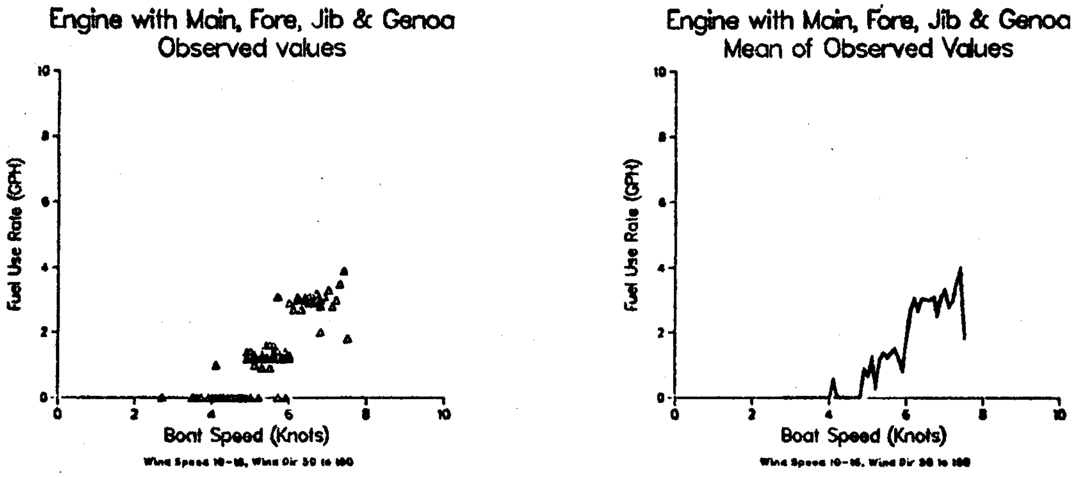
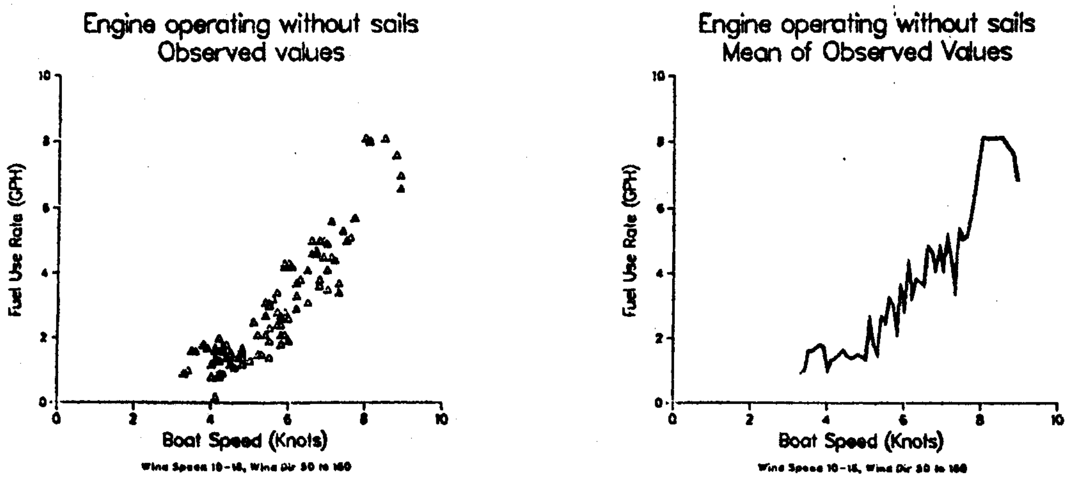


Figure 9 Fuel Use Rate vs Boat Speed



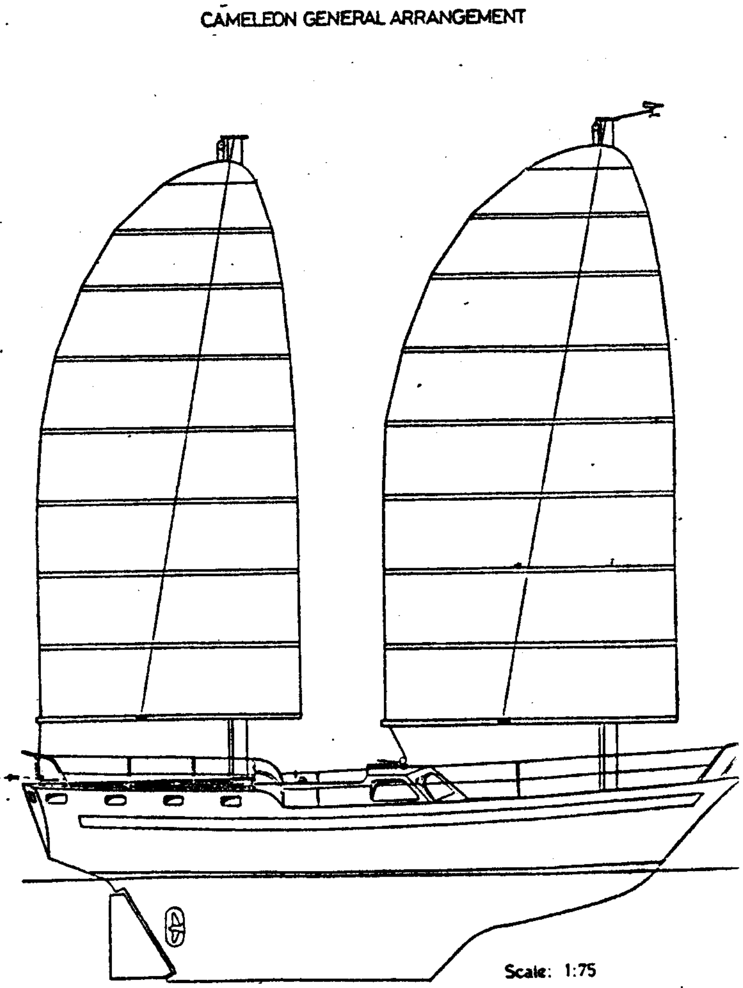


Fig. 11

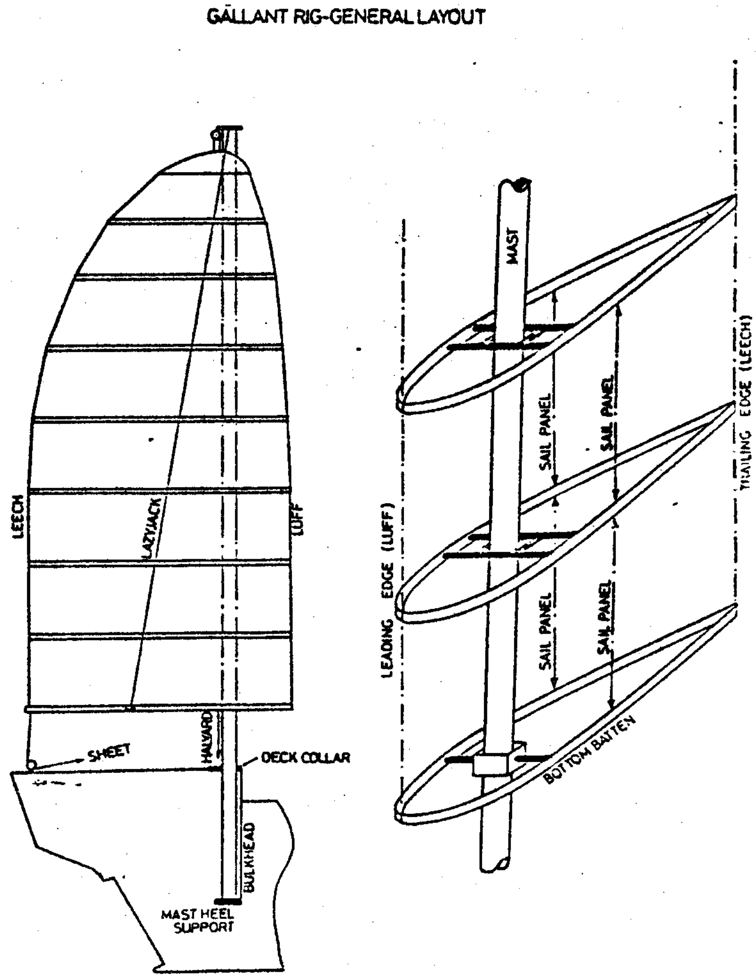


Fig. 12

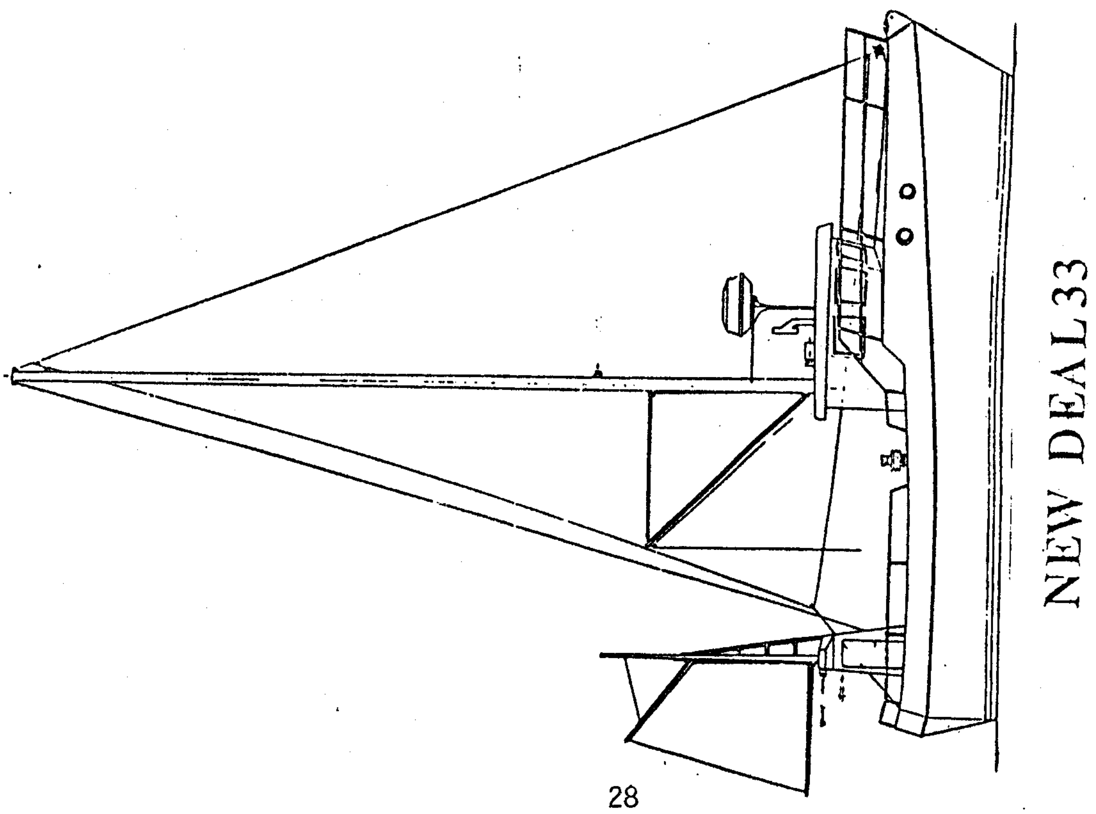


Fig. 10

WIND TUNNEL TEST ON 20 SQ.FT. MODEL OF GALLANT RIG
AT SOUTHAMPTON UNIVERSITY, U.K.: 'AEROSYSTEMS',
KELHAM, DOCK LANE, BEAULIEU, HAMPSHIRE, SO4 7YH
ENGLAND. TEL: 0590 - 612220

Wind Speed: 17 kt. Chord length: 2.6 ft.
Reynolds Number: 500,000

F

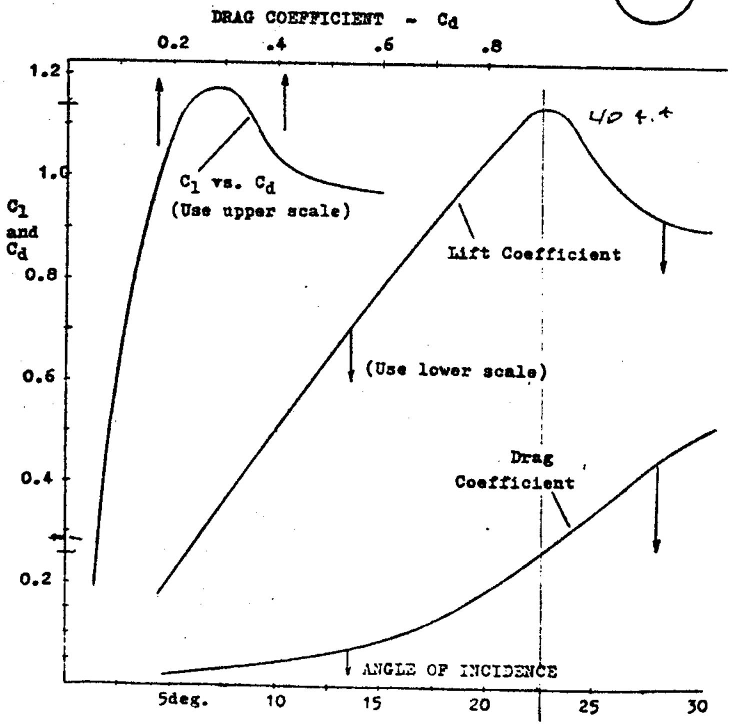
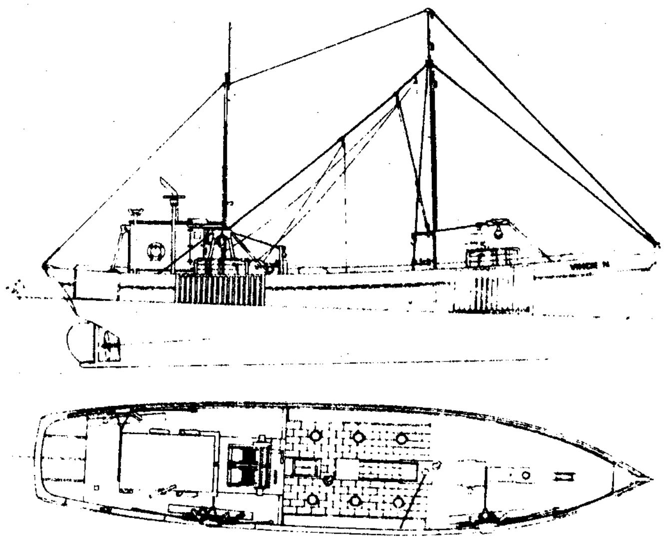


Fig. 13



Outboard profile and deck plan of 86' side trawler Vincie N.
Fig. 14

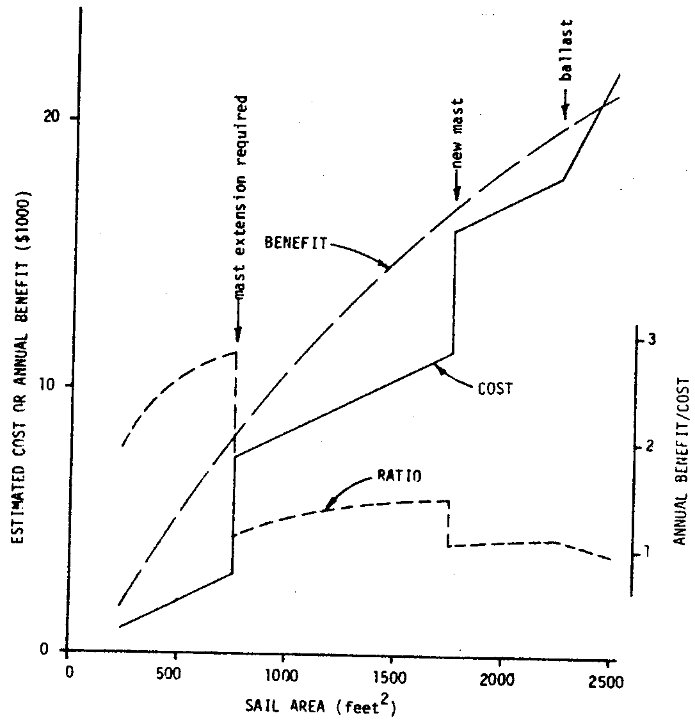


Fig. 15

Costs and economic benefits versus sail area for a hypothetical retrofit sail-assist installation.

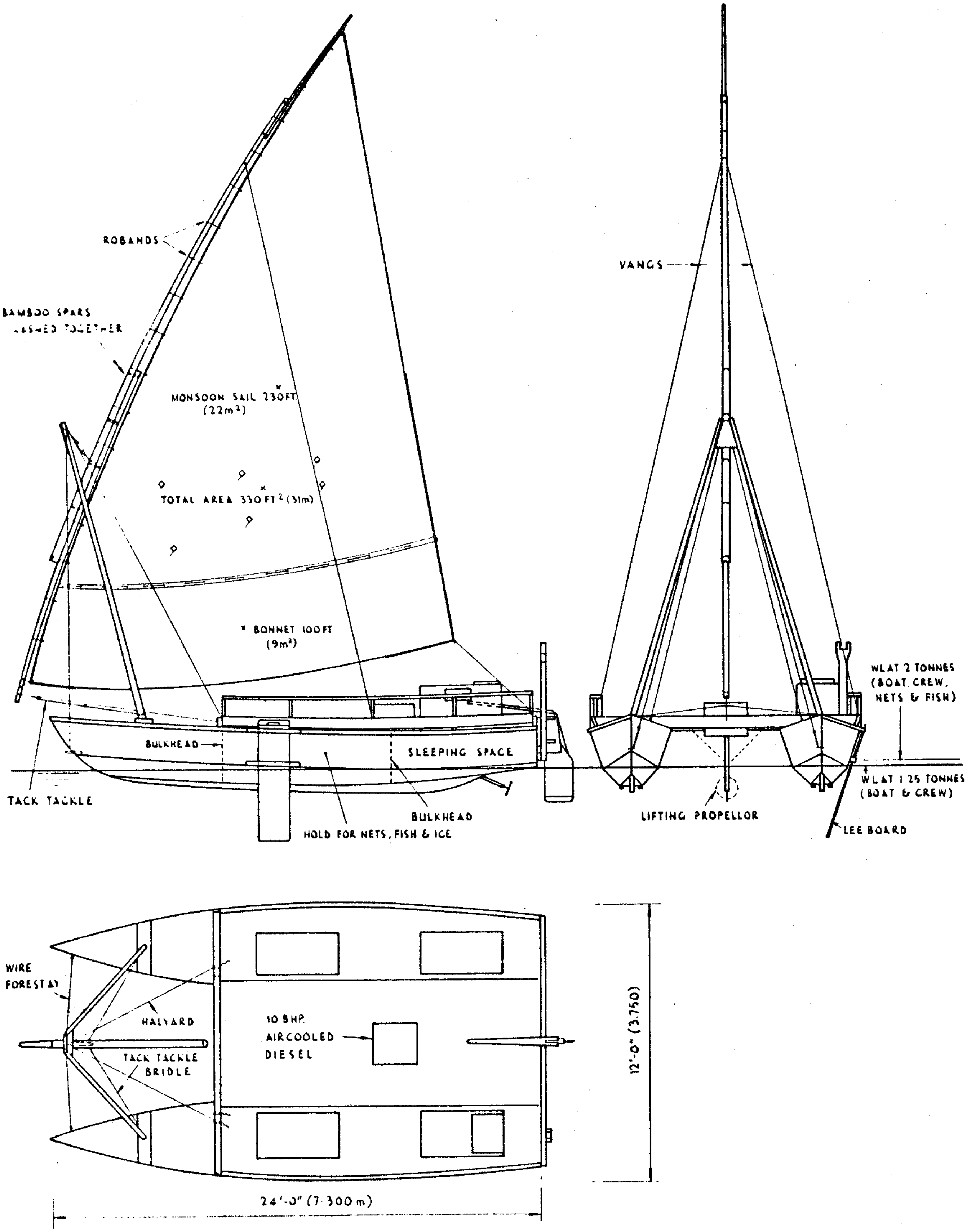
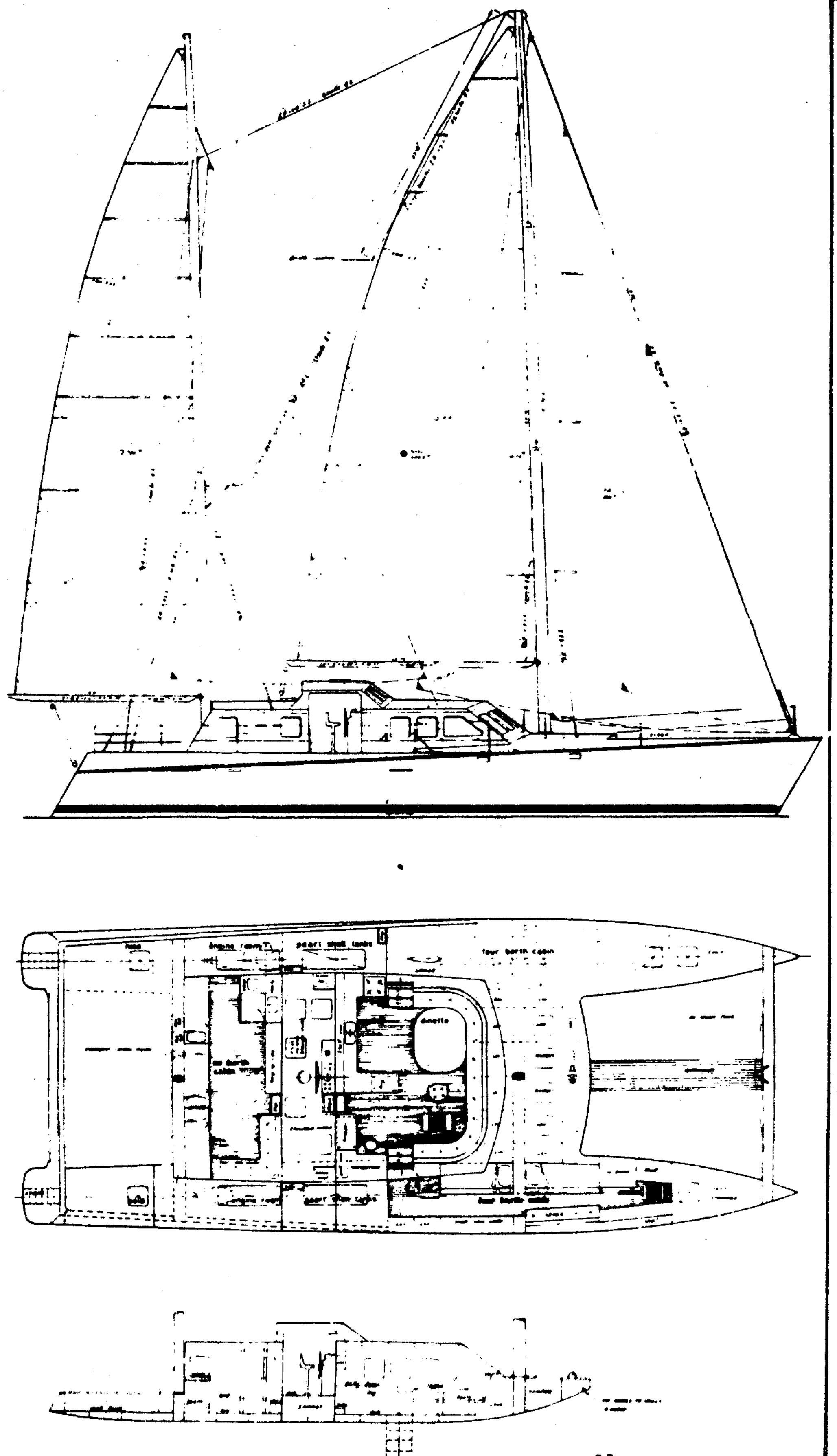


Fig. 16

MODIFIED SANDSKIPPER IN SRI LANKA 1983

DMB



"DMB" SPECIFICATIONS:

Name: "DMB"
Type: Pearlshell diving vessel, carrier boat, accommodation platform and display emporium. All aluminium, diesel powered sailing catamaran.
Owner: Cygnet bay Pearls Pty Ltd, Broome, WA
Designer: Lock Crowther, Turramurra, NSW
Builder: SBF Engineering Pty Ltd, Naval Base, WA
LOA: 73'6"
DWL: 69'.0" (21.03 metres)
Beam OA: 30'9"
Measured depth: 8'9"
Draft DWL: 4'0"
Displacement empty: 38,000lbs, DWL: 60,000lbs, loaded: 78,000lbs
Cargo capacity: 32,000lbs seawater and 4,500lbs pearlshell
HullL/B DWL: 11.68
Power: 2 x 27 shp Perkins diesel engines
Propellers: 2 x variable pitch
Gearboxes: 3:1 reduction
Sail Area: 2443 sq. feet with 1 genoa 2798 sq. feet
Max. stability: DWL 690,000 ft lbs
Cruising speed under power: 9 knots
Range: 1,350 nautical miles
Construction: multi chine welded aluminium to Bureau Veritas and USL
Accommodation: for 14+
Wet tanks: Re-circulating to carry 4,500lbs of live pearlshell
Fishing equipment carried: 'Hookah" diving gear for four peal divers
Area to be fished: North-western Western Australia
Electrical installation: By B&H Electrics of Perth
Hydraulic Equipment: Manufactured and installed by M&J Engineering
Sails and rigging: From Rolly Tasker of Fremantle
Sail Winches: Barlow, Australia — "Handraulic"
Fishing winches: M&J Engineering — Hydraulic
Propellers: Westmeaken controllable pitch from Antelope Engineering, Sydney.
Auxiliary engine: MWM Australia
Aluminium: Comalco
Echo sounder: Furuno color
Radar: JRC
Satnav: NCS
Radio: SSB Codan
Auto pilot: Cetec Benmar

Fig. 17

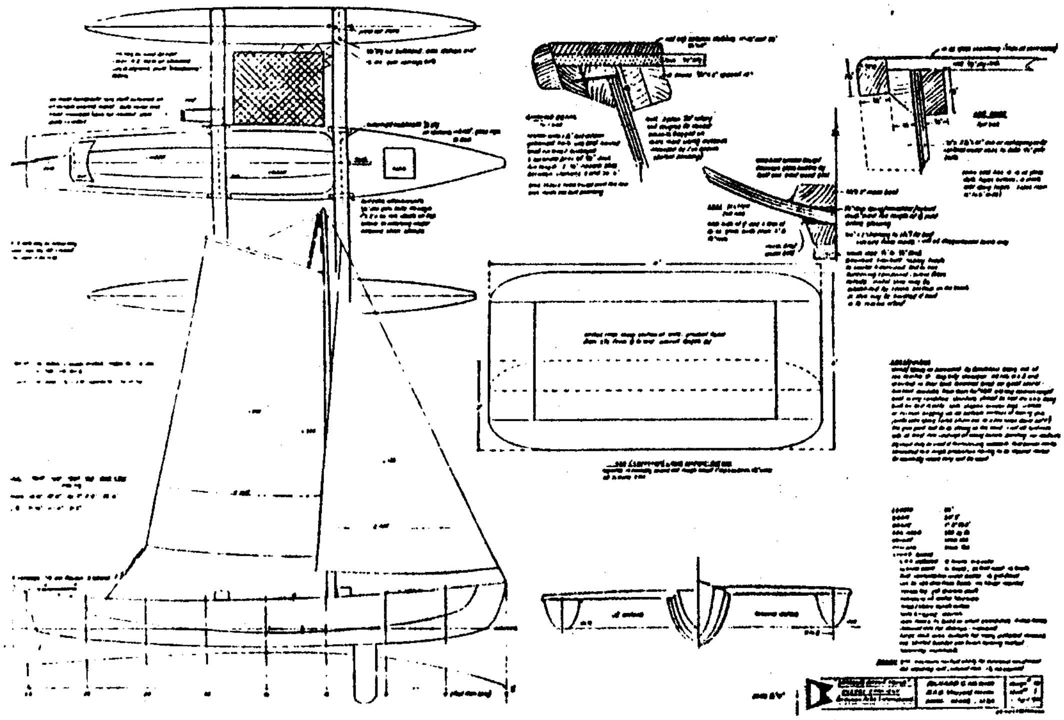


Fig. 18

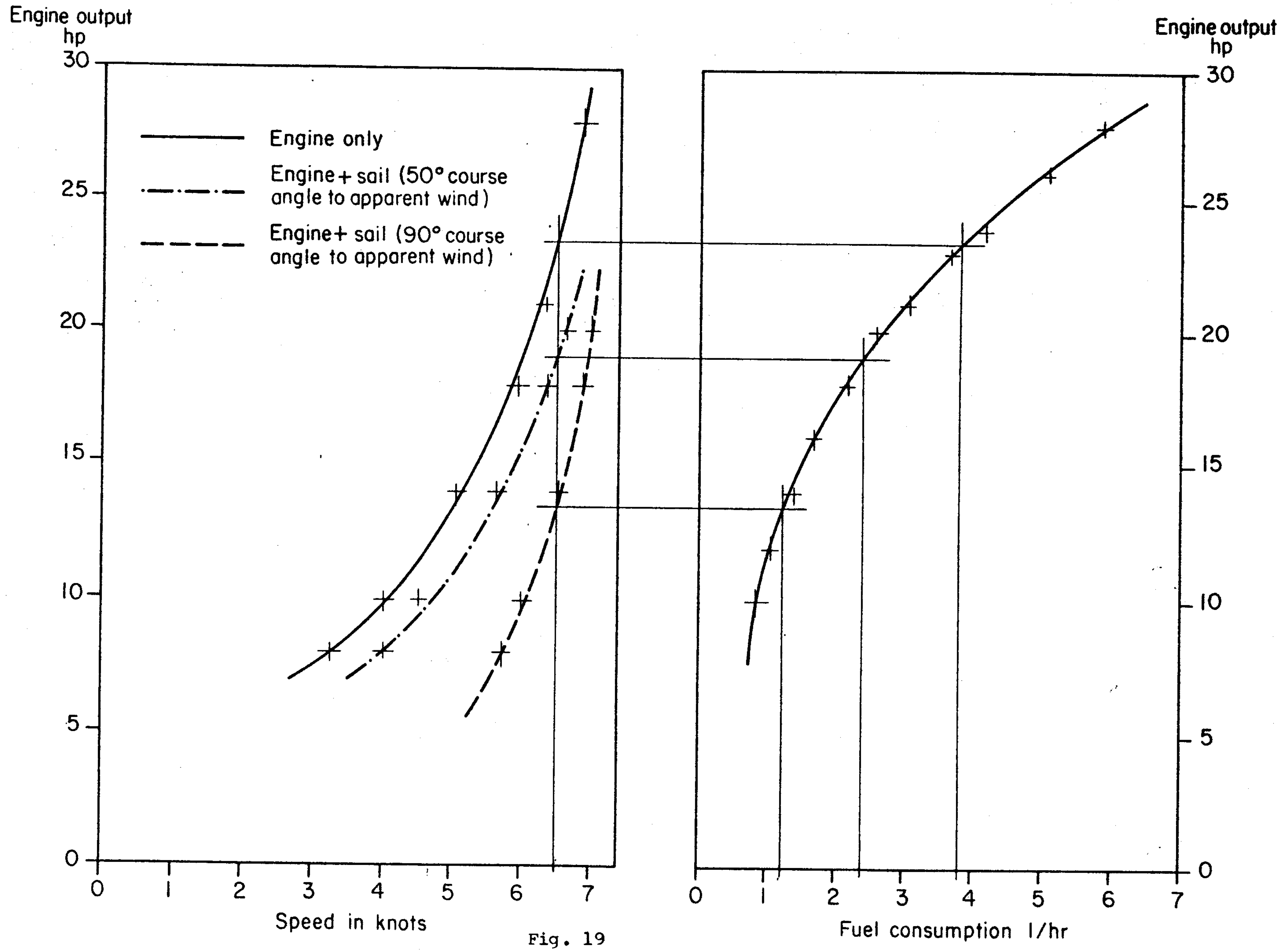


Fig. 19

Estimation of fuel consumption using various combinations of engine and sail power for an 8.5 m (28 ft) fishing boat in Somalia

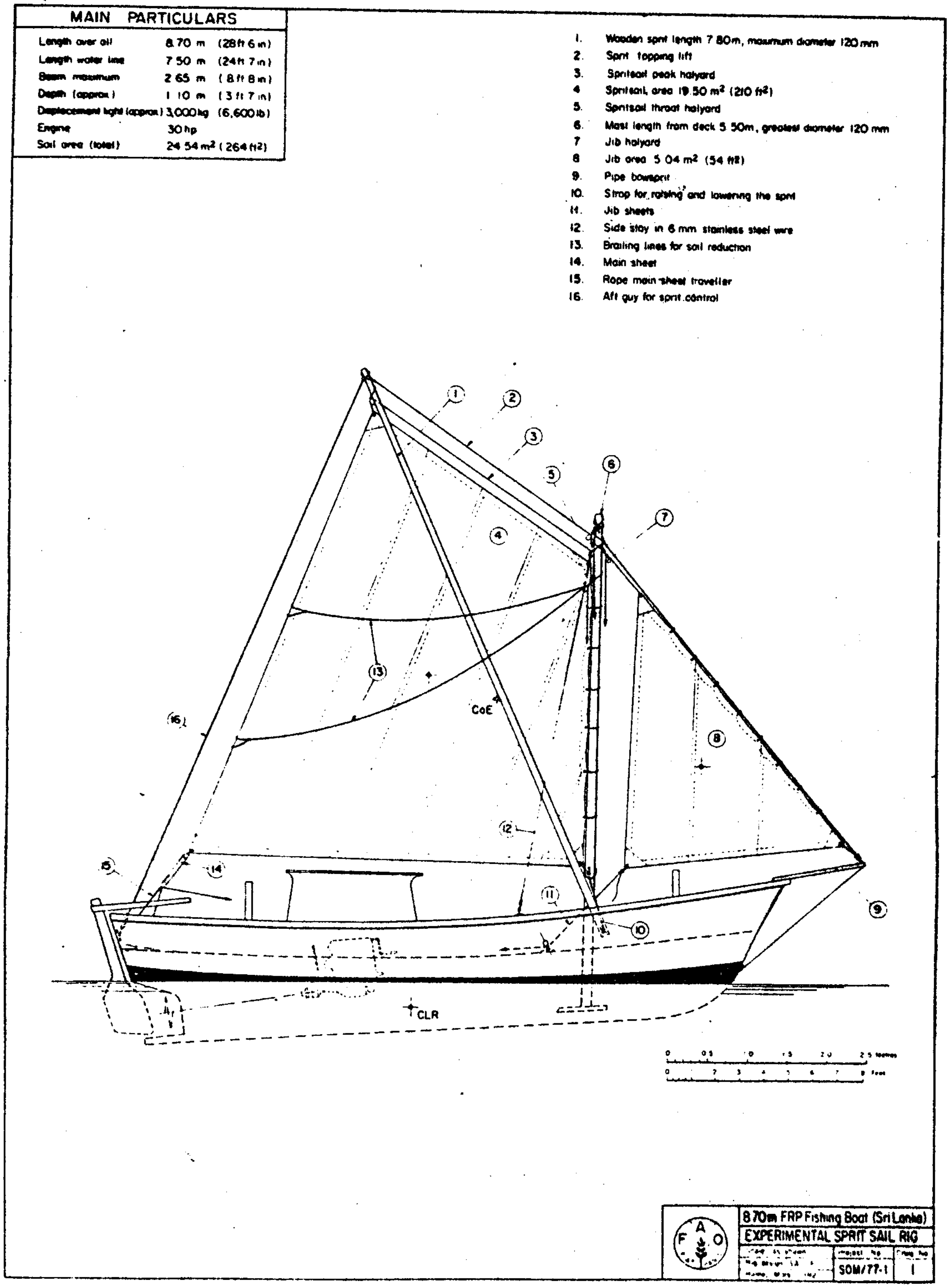

MAIN PARTICULARS
Length over all 8.70 m (28 ft 6 in)
Length water line 7.50 m (24 ft 7 in)
Beam maximum 2.65 m (8 ft 8 in)
Depth (approx) 1.10 m (3 ft 7 in)
Displacement light (approx) 3,000 kg (6,600 lb)
Engine 30 hp
Sail area (total) 24.54 m² (264 ft²)
1. Wooden sprit length 7.80 m, maximum diameter 120 mm
2. Sprit topping lift
3. Spritsail peak halyard
4 Spritsail, area 19.50 m² (210 ft²)
5. Spritsail throat halyard
6. Mast length from deck 5.50 m, greatest diameter 120 mm
7 Jib halyard
8 Jib area 5.04 m² (54 ft²)
9. Pipe bowsprit
10. Strop for raising and lowering the sprit
11. Jib sheets
12. Side stay in 6 mm stainless steel wire
13. Brailing lines for sail reduction
14. Main sheet
15. Rope main-sheet traveller
16. Aft guy for sprit control
CoE
CLR
8.70m FRP Fishing Boat (Sri Lanka)
EXPERIMENTAL SPRIT SAIL RIG
SOM/77-1
1

Fig. 20

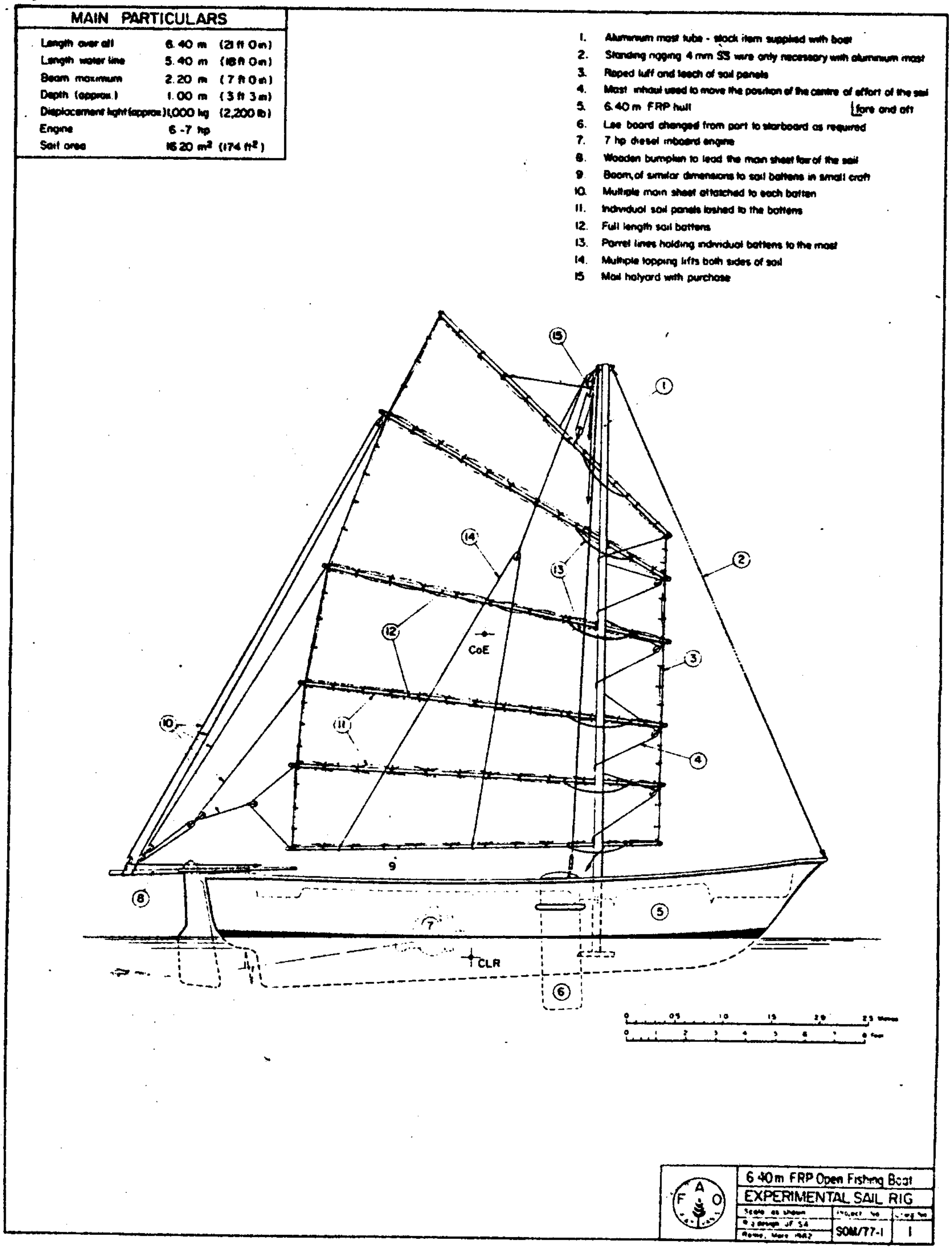


Fig. 21 Arrangement and sail plan

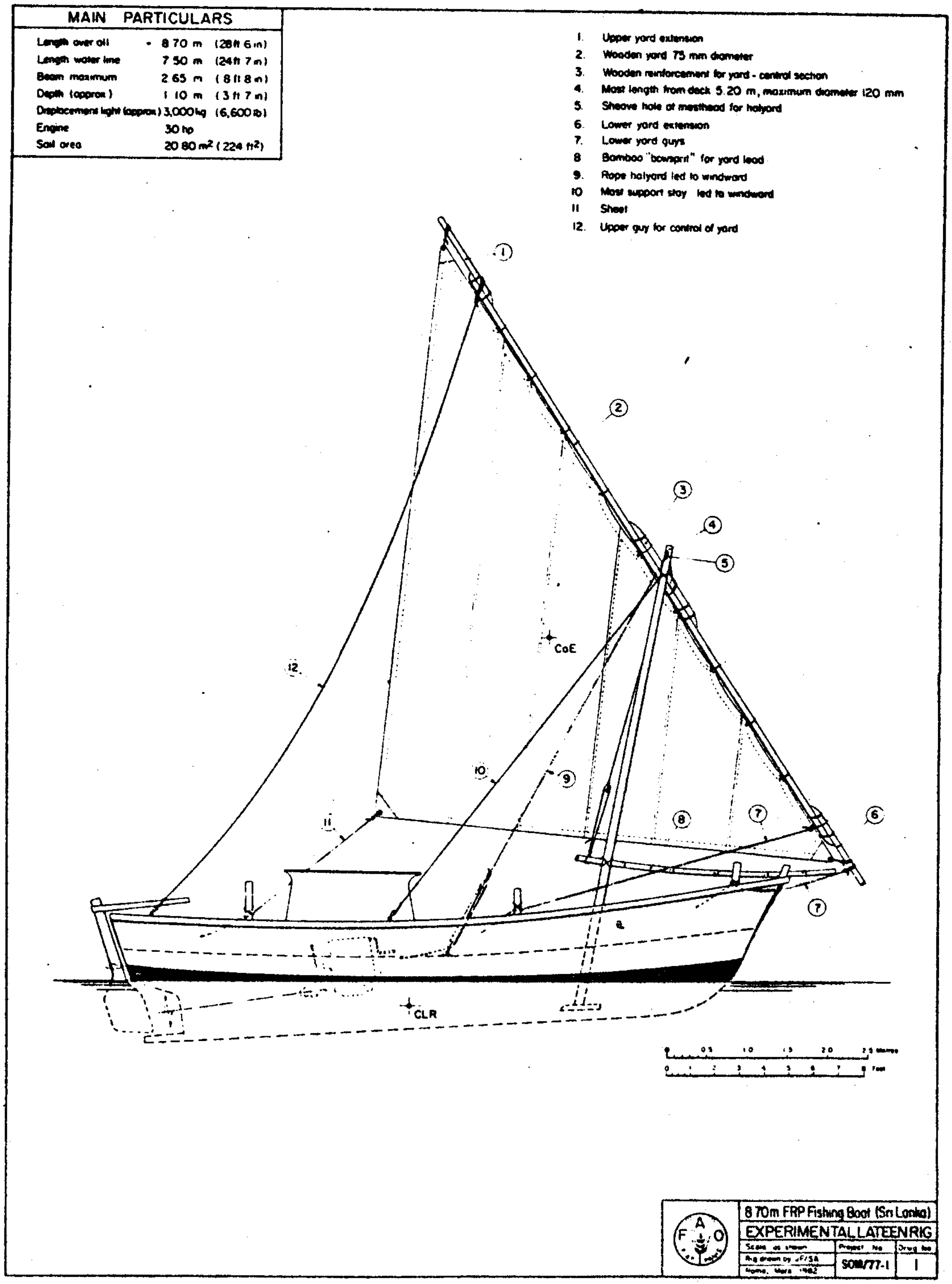
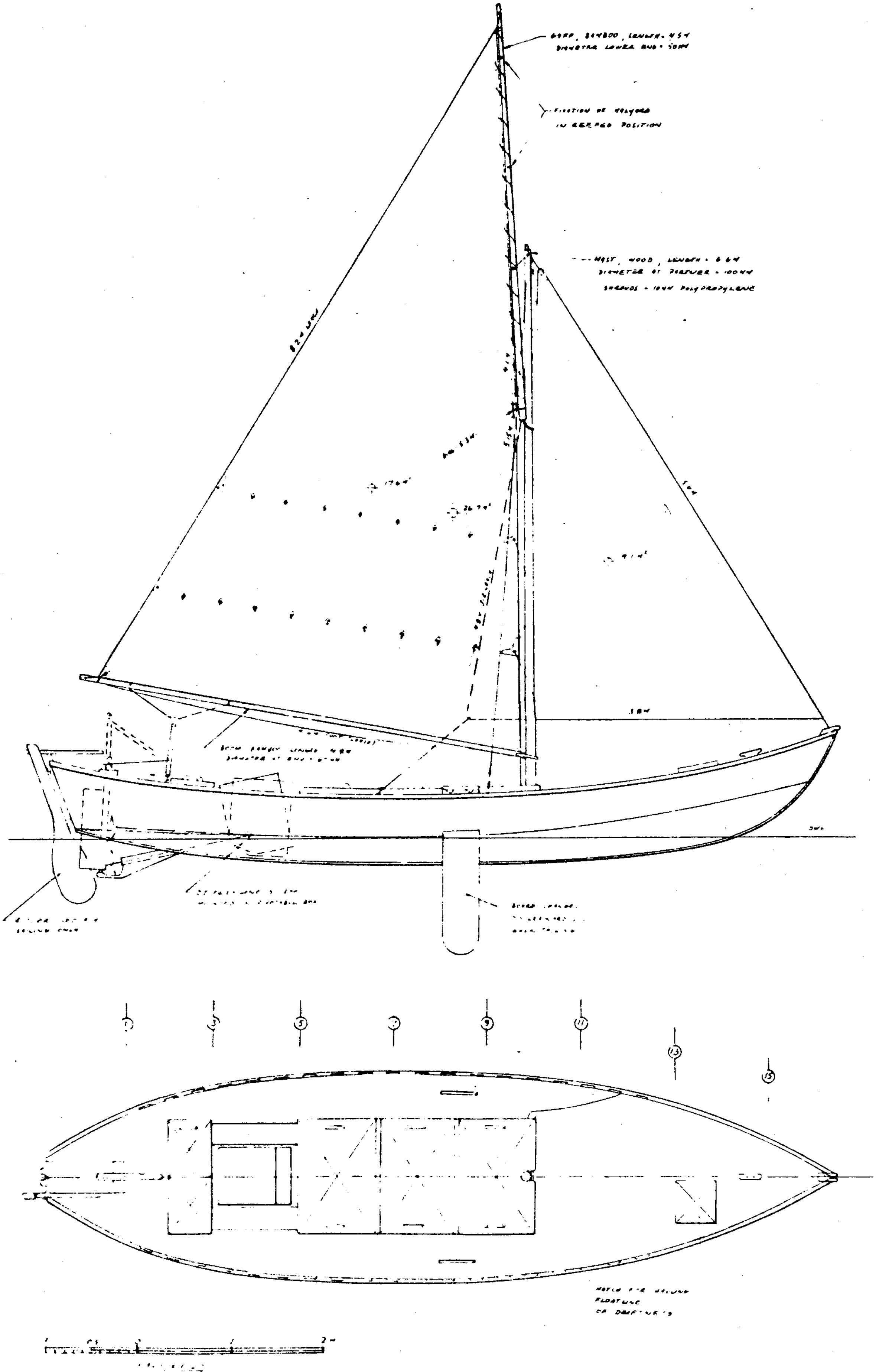


Fig. Lateen rig fitted to the same hull as that of Fig.

Fig. 22



A gunter rig used on an 8.4 m (28 ft) beach landing craft in India.

Fig. 23

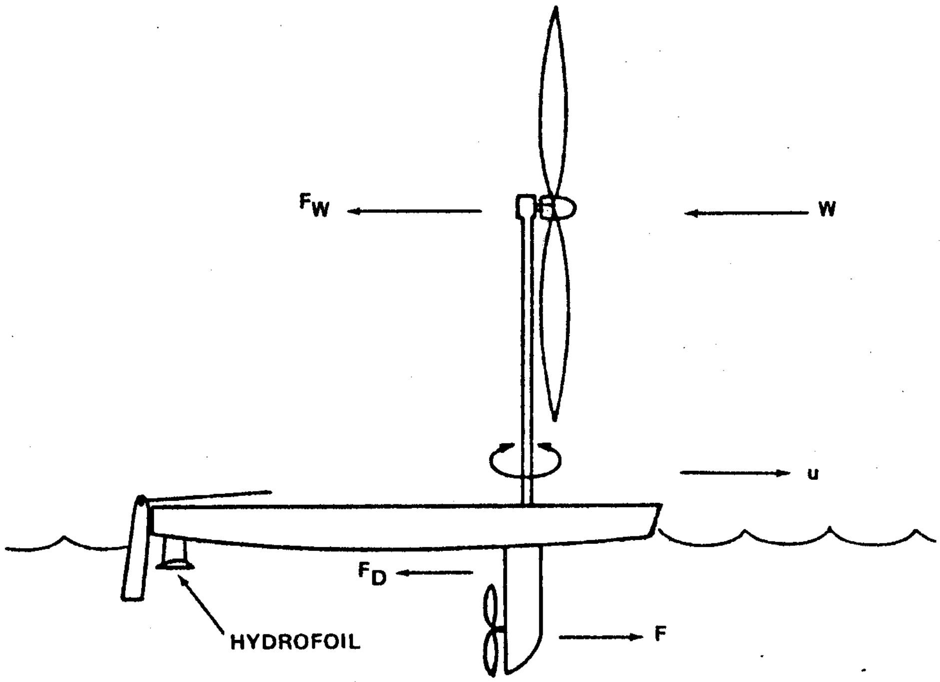
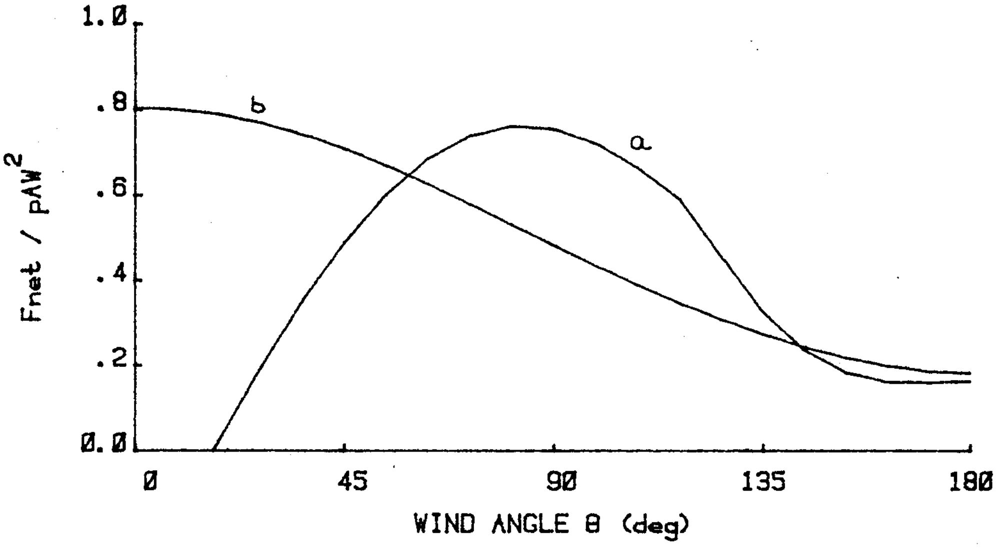
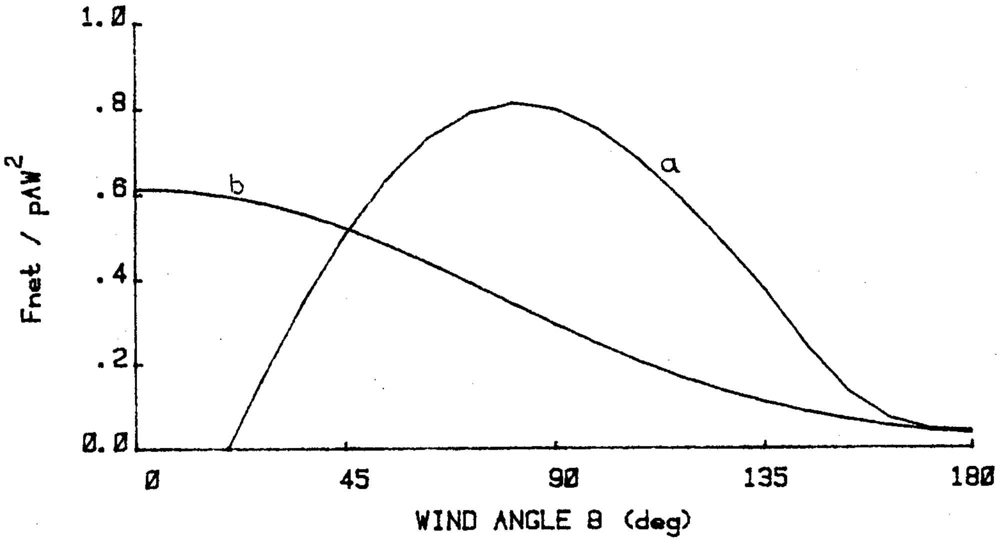


Figure : Dalhousie University windmill boat (catamaran) sailing straight upwind. The wind turbine can be rotated about the vertical mast so as to face the apparent wind, allowing the boat to be sailed in any direction without tacking. F_W is the backward force on the wind turbine. F is the forward force produced by the underwater propeller and F_D is the drag force of the water on the boat. The net force ($F-F_W$) produces the forward speed, u, of the boat, at which $F-F_WF_D = 0$. The underwater hydrofoil at the rear of the boat counteracts the rearward pitching moment due to the forces F_W, F and F_D. (10).

Fig. 24

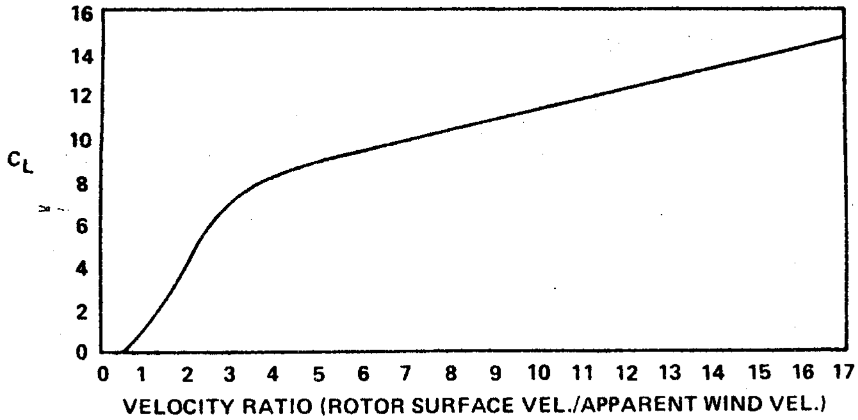


Normalized net forward force versus wind angle θ for an aerofoil sail (a) and a windmill thruster (b). The boat is travelling at u = 0.5W.



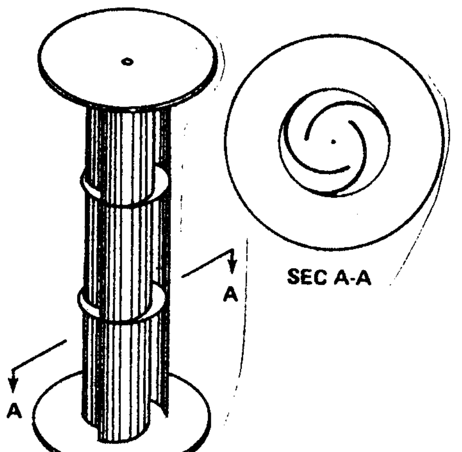
Same as Fig. (4), but with u = 0.75W.

Fig. 25



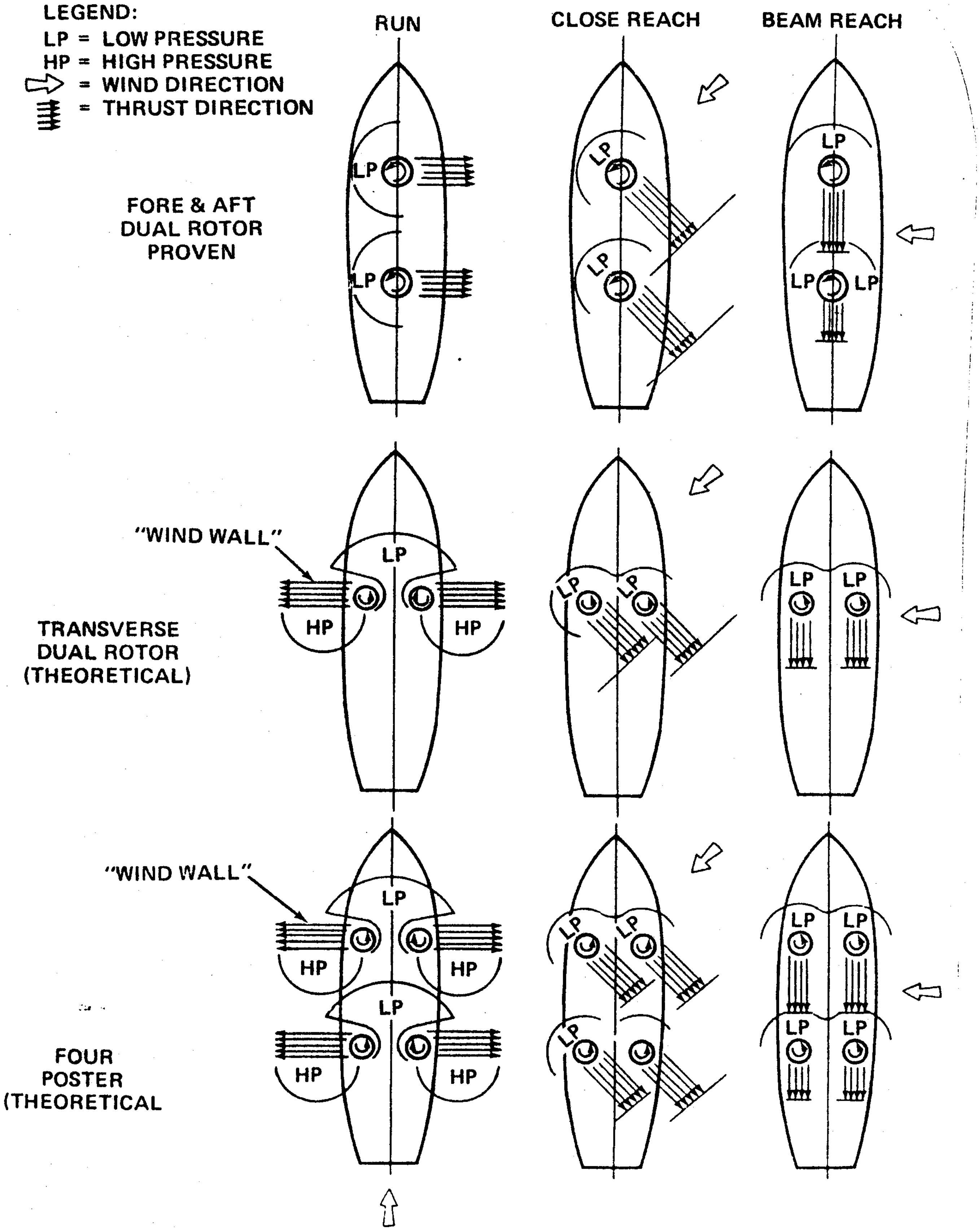
Magnus Rotor Lift vs Velocity Ratio (Experimental).

Fig. 26

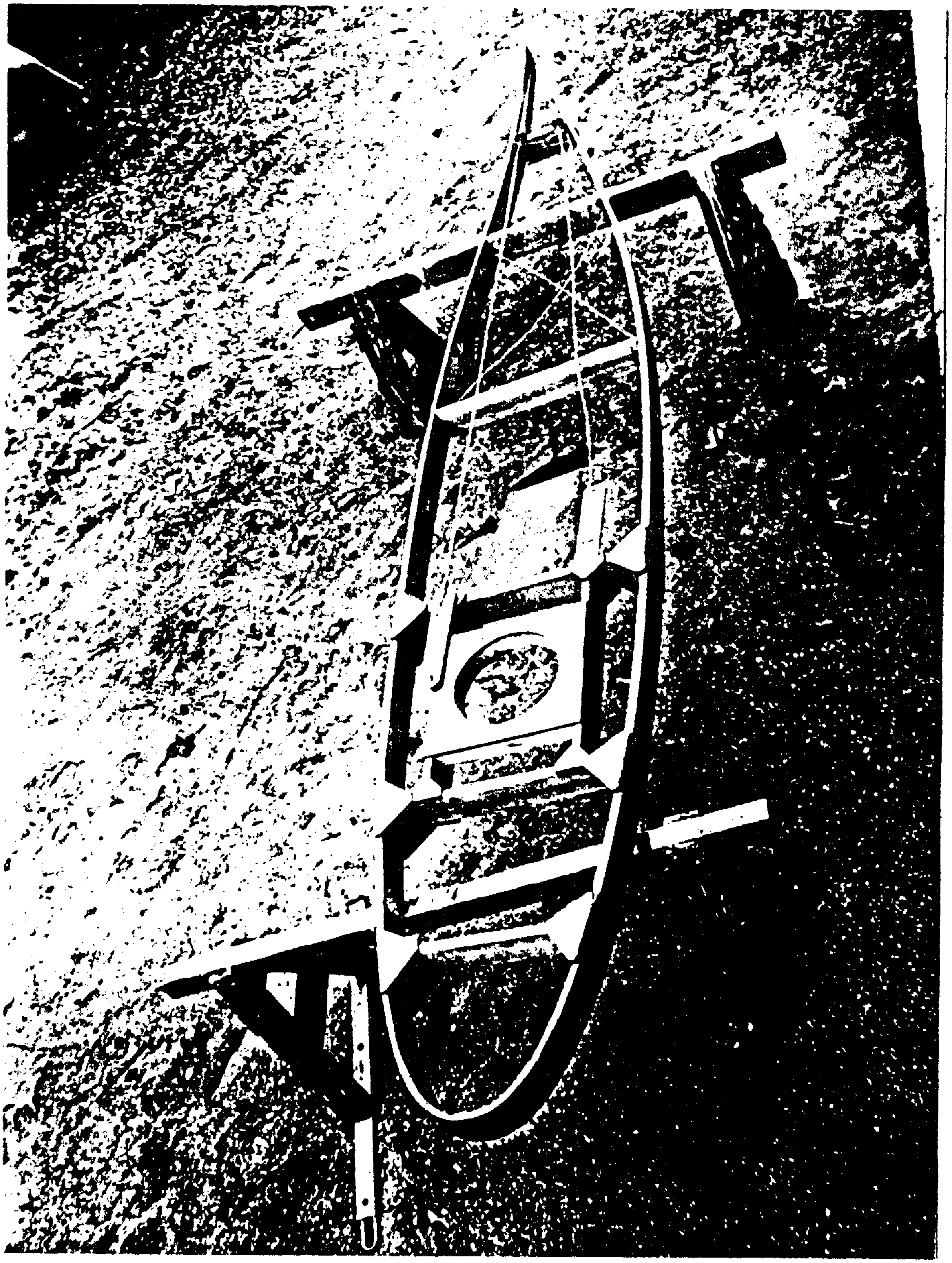


Self Starting, Auto-Rotating Magnus Effect Rotor (Borg/Luther February 17, 1983).

Fig. 27



Magnus effect (Flettner) rotor arrangements. The fore and aft arrangement is the one used by Flettner on BADEN-BADEN and BARBARA (2). The transverse and "four poster" arrangements are theoretical (Borg/Luther February 17, 1983). Fig. 28



BATTEN WARPED TO NASA GA(W) 1 PROFILE

Fig. 29

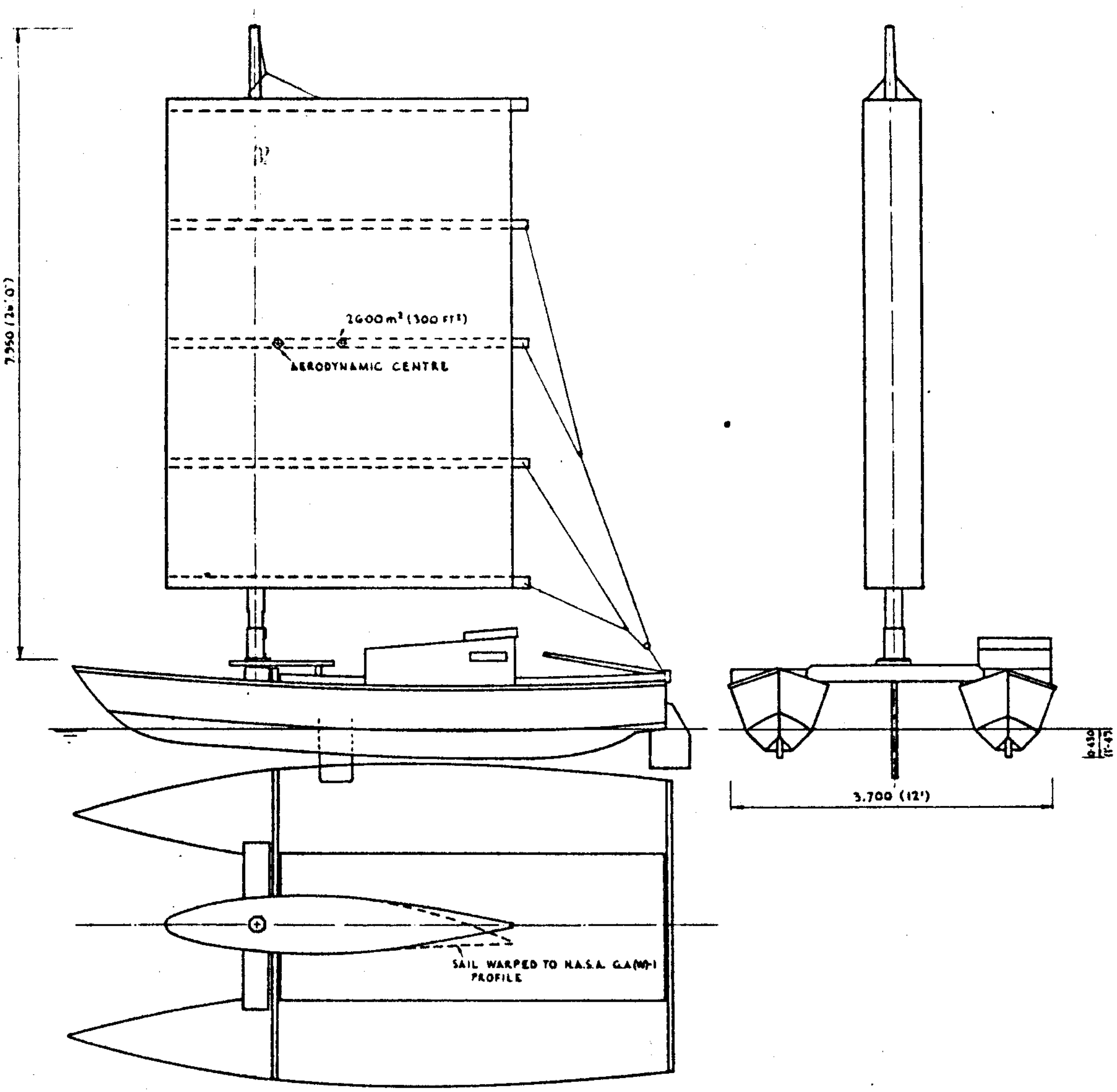
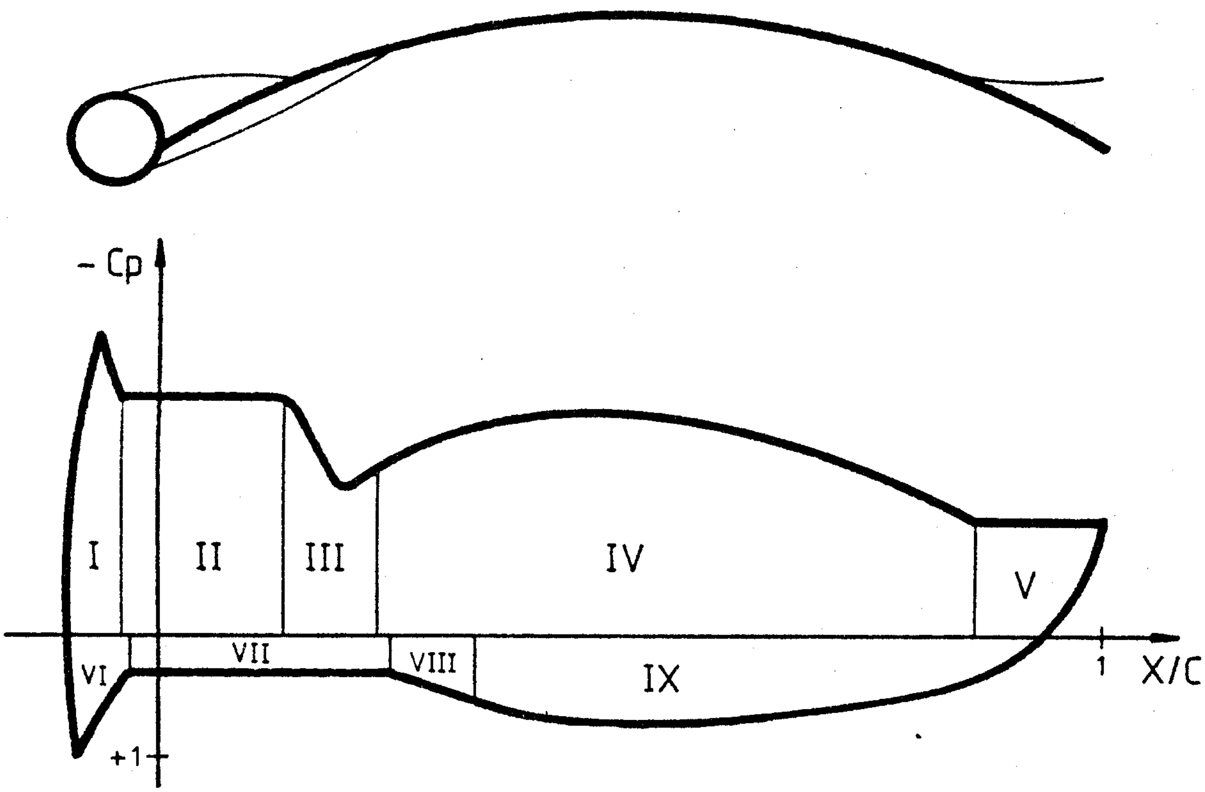
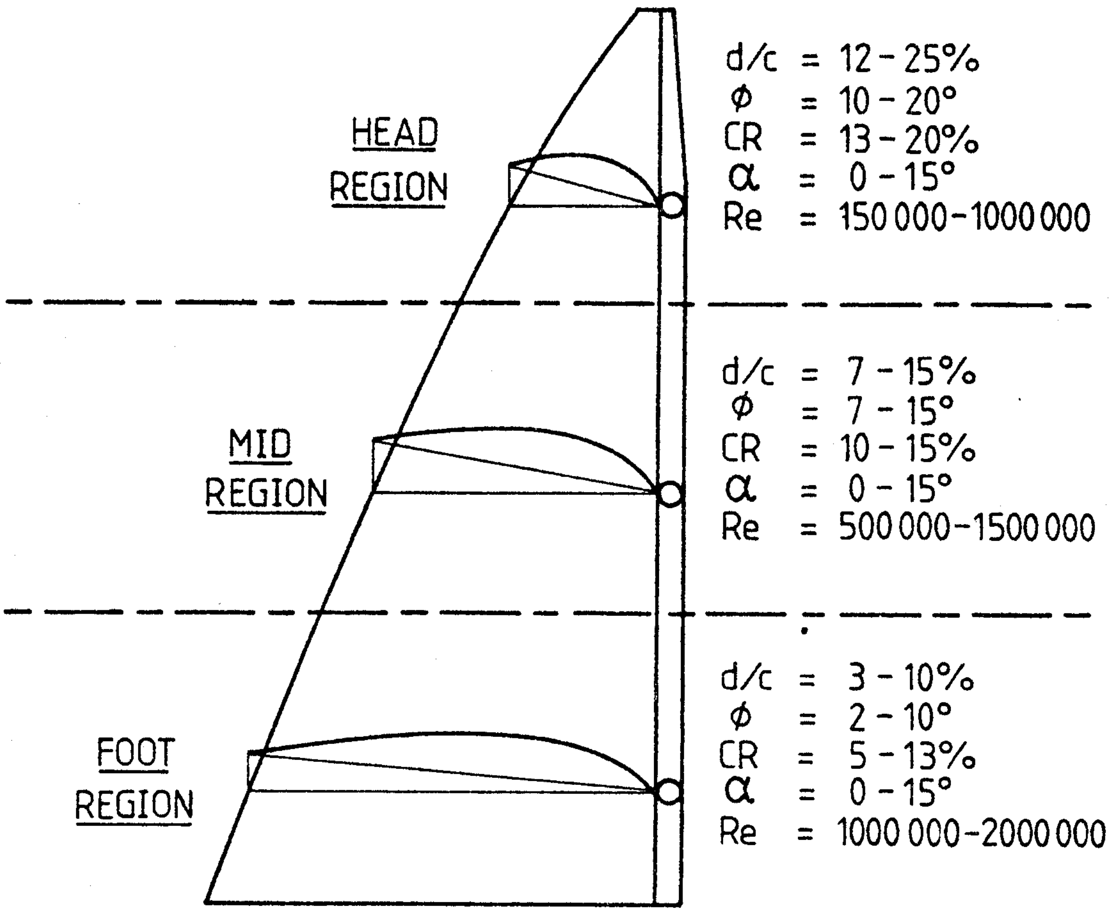


FIG. 30 EXPERIMENTAL TUNNY RIG ON SANDSKIPPER



REGION	DESCRIPTION
I	Upper Mast Attached Flow Region
II	Upper Separation Bubble
III	Upper Reattachment Region
IV	Upper Aerofoil Attached Flow Region
V	Trailing Edge Separation Region
VI	Lower Mast Attached Flow Region
VII	Lower Separation Bubble
VIII	Lower Reattachment Region
IX	Lower Aerofoil Attached Flow Region

Fig(31) Universal Pressure Distribution

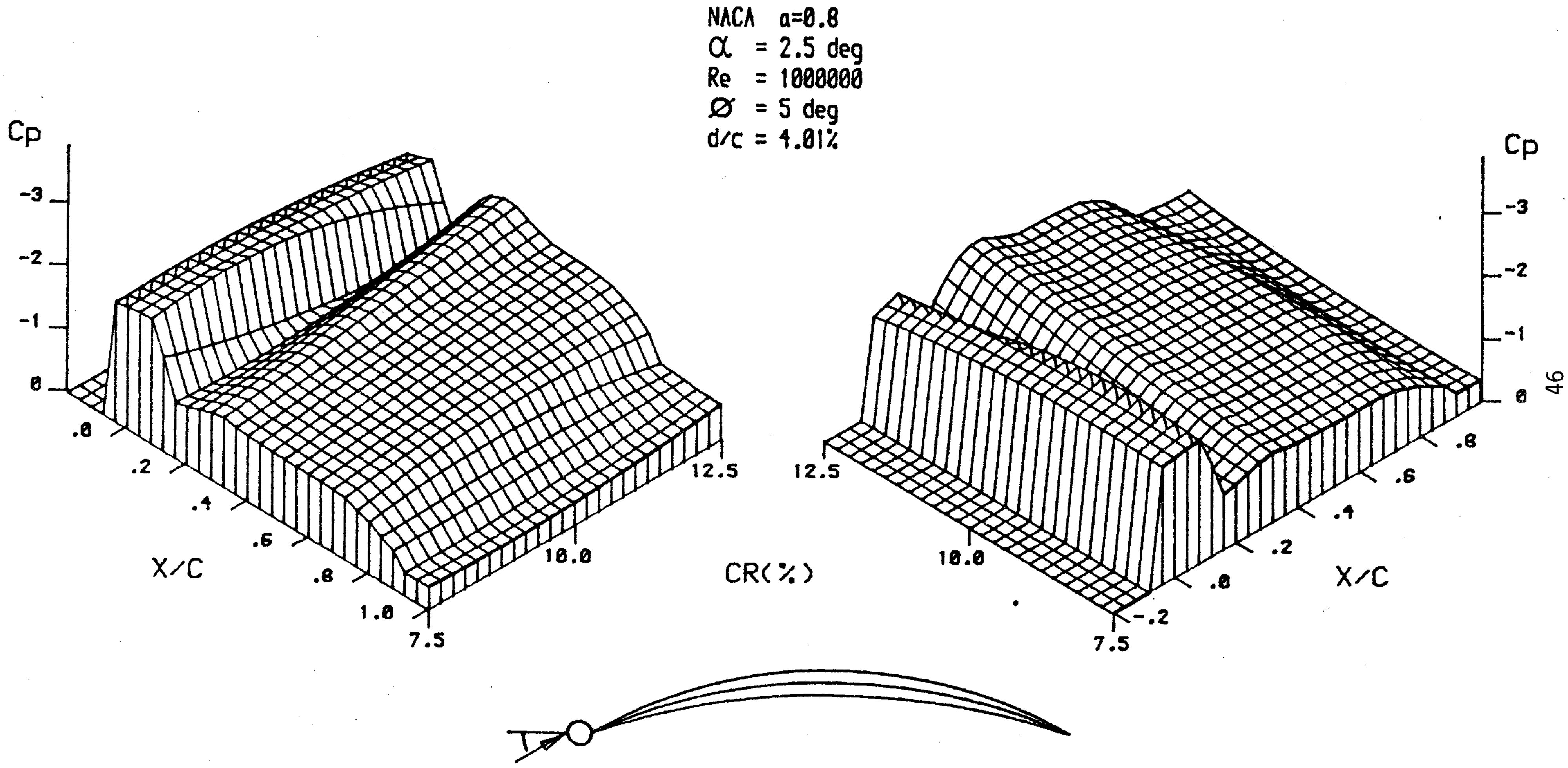


Fig(3) Typical Parameter Ranges Across a Mainsail

<table>
<tr><th></th><th colspan="12">HEAD REGION</th><th colspan="12">MID REGION</th><th colspan="12">FOOT REGION</th></tr>
<tr><td>d/c (%)</td><td colspan="12">17</td><td colspan="12">10</td><td colspan="12">4</td></tr>
<tr><td>φ (°)</td><td colspan="12">15</td><td colspan="12">10</td><td colspan="12">5</td></tr>
<tr><td>CR (%)</td><td colspan="4">12·5</td><td colspan="4">15·0</td><td colspan="4">17·5</td><td colspan="4">10·0</td><td colspan="4">12·5</td><td colspan="4">15·0</td><td colspan="4">7·5</td><td colspan="4">10·0</td><td colspan="4">12·5</td></tr>
<tr><td>Re x 10^5</td><td colspan="4">3·5</td><td colspan="4">6</td><td colspan="4">10</td><td colspan="4">6</td><td colspan="4">10</td><td colspan="4">14</td><td colspan="4">10</td><td colspan="4">14</td><td colspan="4">16</td></tr>
<tr><td>α (°)</td><td colspan="3">2·5</td><td colspan="3">5</td><td colspan="3">7·5</td><td colspan="3">10</td><td colspan="3">2·5</td><td colspan="3">5</td><td colspan="3">7·5</td><td colspan="3">10</td><td colspan="3">2·5</td><td colspan="3">5</td><td colspan="3">7·5</td><td colspan="3">10</td></tr>
</table>

Fig. 32

Parameter Values Tested



Fig(33) Evolution of Static Pressure Distribution with Changing Camber Ratio

THE NEW DEAL 33 - A SCANDINAVIAN SAIL-ASSISTED FISHING BOAT

Arnt Amble, Dr.ing.
Nordland Research Institute
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ABSTRACT

A series of 33 ft. sail-assisted GUP fishing vessels designed by the swedish yacht designer Peter Norlin is now being produced by the norwegian boat-building firm A.S. Mørebas. Experience from fast sailing yachts has been used to design a fishing vessel with very low hull resistance. The sail configuration is designed for easy operation by a small crew and consists of a large furling genoa together with a traditional gaff mizzen. In order to maximize the propeller efficiency, the propulsion plant incorporates a large, slow-rotating propeller driven through a gear of high reduction rate. The vessel is designed for hand lines, longline or gill netting operation. Initial performance tests indicate considerable fuel savings compared to traditional vessels of similar size and speed.

INTRODUCTION

In Norway, fishing vessels were sailing vessels for more than a thousand years - and only 70 years ago they still were. But since then the diesel engine has taken over and sail for propulsion has not been seen on fishing vessels since about 1940. But what is happening now? The rapid increase of fuel prices throughout the last 10 years has had serious negative effects on the running economy of fishing vessels, also in Norway. Bad economy in fisheries tend to have the effect that less fishermen purchase new vessels. To stand up to this situation on the market, the boat-building firm A.S.Mørebas of Molde, Norway a few years ago found that they had to reshape their production program. Among other things, it was decided to develop a fishing vessel designed for sail-assisted propulsion.

DESIGN

The task of designing the vessel was given to Peter Norlin in Stockholm, one of Scandinavia's leading designers of sailing yachts. He has designed a wide range of sailing yachts, both one-offs (like Swedish Entry for the last Whitbread Round the World Race) and production boats having been manufactured in great numbers, most of them sailing in Scandinavian waters (types like Scampi, Accent, Omega 42, Albin Express/Cirrus/Cumulus/Delta/Nova/Stratus and many others). He used his skill and experience to come up with a fishing vessel having a general arrangement rather similar to other modern small Norwegian fishing vessels. But underwater hull lines are very smooth and slender compared to conventional fishing boat hulls - giving very low resistance. This, together with a keel design giving sail-carrying and windward-going ability, has resulted in a fishing boat suitable for sail, motor or combined propulsion.

RIG AND SAIL

For ease of operation the sail configuration is very simple, consisting only of a large furling genua and a small gaff mizzen. The gaff mizzen is a standard sail on almost all smaller fishing boats in norwegian waters, having the purpose of keeping the vessel steadily head-to-wind when hauling gill nets or longline. The furling genua can be used either fully extended or reefed down to whatever reduced sail area that conditions may require. The headstay furling system enables quick and easy reefing and taking in sail.

The vessel is shown in Fig. 1. Main dimensions are:

Length o.a.	10.00 m	(33 ft)
Bream:	3.16 m	(10 ft)
Draught:	1.45 m	(5 ft)
Sail area:		
Genua	42.0 sq.m	(450 sq.ft)
Mizzen	5.0 sq.m	(53 sq.ft)
Displacement:	7 tons	

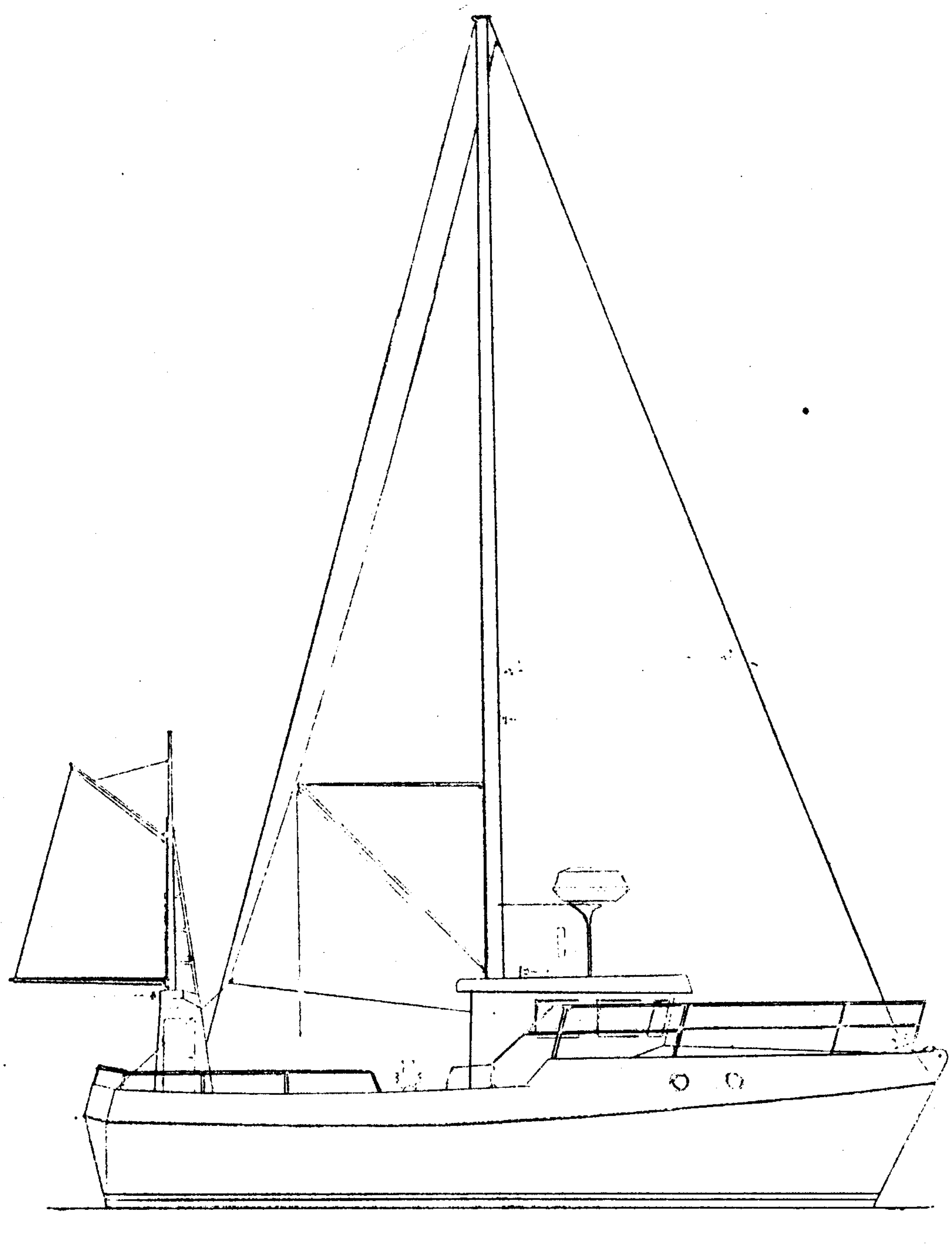

Fig.1. New Deal 33.

PROPULSION PLANT

Although the use of sail implies possible fuel savings of considerable amount, other means to increase the propulsion efficiency should not be neglected. For this reason, a large-diameter (D=850 mm) two-bladed controllable pitch propeller has been designed for the New Deal 33. By means of a reduction gear with a large gear ratio (about 5:1), an engine installation of 30-40 Hp is enough to give ample power and speed.

The vessel can also be delivered more like a traditional non-sail fishing boat, with the same machinery but without the sailing rig (Fig. 2).

DECK ARRANGEMENT AND ACCOMODATION

As usual on modern norwegian fishing vessels of this size, the wheelhouse is located well forward, giving ample working deck area aft of the wheelhouse. The vessel can be arranged for gill netting, longlining or for 3 to 5 automatic hand line haulers, to mention three of the most common fishing methods used by vessels of this size in Norway.

The wheelhouse is unconventionally large, giving room also for the pantry and a dinette table. Down below in the forward cabin there are four bunks and a separate toilet & shower compartment.

INITIAL TEST RESULTS

On the prototyp vessel, with a 40 hp Perkins diesel installed, initial measurements of performace and fuel consumption have been carried out by the engine supplier.

Without using the sail, and loaded to a displacement of 8.4 tons, a speed of 8.2 knots is obtained while consuming 8.23 litres/hour or 1.0 litres per nautical mile, according to the test report. A cruising speed of 7.7 knots is maintained consuming 5.85 litres/hour

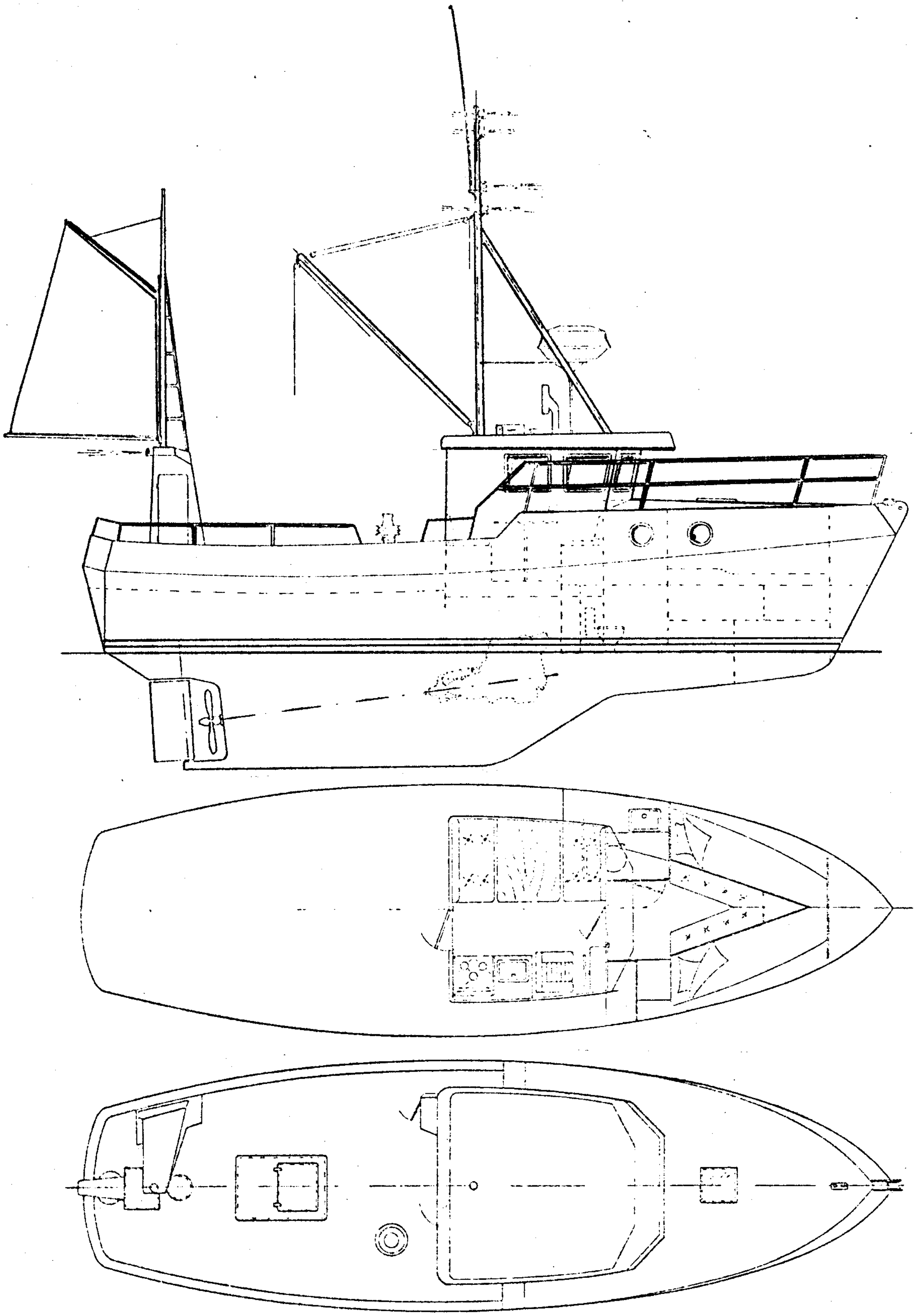

Fig.2. New Deal 33 without sail rig.

or 0.76 litres per nautical mile.

Loaded to a displacement of 12 tons, a speed of 8.0 knots is obtained consuming 9.41 litres per hour or 1.18 litres per nautical mile. 7.6 knots is maintained at a consumption of 6.0 litres per hour or 0.79 litres per nautical mile.

Conventional norwegian fishing vessels of similar size and displacements normally have engine installations of 80-120 Hp, consuming 15 to 25 litres per hour to obtain speeds round 8 knots. Consequently, even without sail power, the hull and propeller efficiency of the New Deal concept give room for substantial fuel savings.

FURTHER TEST PROGRAM

A further performance test program to be carried out by Nordland Research Institute has been set up. For this test, vessel number 5 of the New Deal 33 production series is being used, with a 30 hp norwegian Sabb diesel engine installed. The necessary onboard instrumentation is being set up just now.

The test program has an emphasis on quantyfying the fuel savings obtainable by sail assistance, for various wind conditions. The following parameters will be varied:

- Loading conditions
- Wind speeds
- Vessel headings relative to wind
- Sail area
- Propeller pitch and speed.

A microcomputer is being installed onboard, to receive and process data from the following instruments:

- Wind speed meter
- Wind direction indicator
- Compass

- Speed log
- Engine RPM indicator
- Fuel consumption meter.

The test program is scheduled to be carried through within the end of next month, if wind conditions permit and unexpected difficulties are not met.

APPENDIX: FUEL CONSUMPTION MEASUREMENT RESULTS

Conditions	Engine RPM	Speed (knots)	Fuel consumption (l/h)	(l/n.m.)
Displacement=8.4 tons Propeller pitch giving RPM max=2075 No sail	2075 1956 1838 1578 1424	8.3 8.17 8.0 7.6 7.2	9.92 8.78 7.54 5.48 4.38	1.20 1.07 0.94 0.72 0.61
Displacement=8.4 tons Propeller pitch giving RPM max=1600 No sail	1600 1424 1230	8.2 7.7 7.35	8.23 5.85 4.83	1.00 0.76 0.66
Displacement=12.0 tons Propeller pitch giving RPM max=2075 No sail	2075 1810 1580 1424	8.0 7.6 7.2 6.8	9.41 6.0 4.54 2.87	1.18 0.79 0.63 0.42
Displacement=12.0 tons Propeller pitch giving RPM max=1594 No sail	1594 1417 1217 1002	7.8 7.5 7.0 6.1	7.54 5.0 3.82 2.59	0.97 0.67 0.55 0.42

All measurements were made by Mr. Knut Johnsen of Universal Diesel A/S, Oslo.

BIOGRAPHIC SKETCH

Arnt Amble graduated from the Norwegian Institute of Technology, Trondheim, Norway in 1971 as a Master of Science in Naval Architecture and Marine Engineering. He got his Dr.ing. degree with a major in

Fishing Vessel Design from the same institution in 1977. He is presently with the Nordland Research Institute in Bodø, Norway as a research manager in fisheries technology. Sailing has always been one of his favourite hobbies and at the moment he is the chairman of the local sailing club in Bodø.

APPROPRIATE SAILING RIGS FOR ARTISANAL FISHING CRAFT IN DEVELOPING NATIONS

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MacAlister Elliott and Partners, Ltd., U.K.

and

J.F. Fyson
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Food and Agriculture Organization of the United Nations
Rome, Italy

SYNOPSIS

The plight of many subsistence and artisanal fisheries, caused by fuel costs and mechanisation problems, is described. The authors, through experience of practical sail development projects at beach level in developing nations, outline what can be achieved by the introduction of locally produced sailing rigs and discuss the choice and merits of some rig configurations.

CONTENTS

1. INTRODUCTION

Small-scale artisanal fisheries of the developing countries produce at least one third of the annual world food fish catch of some 55 million tons. Between 20 and 30 million artisanal fishermen, their dependents, traders and distributors, depend on small-scale fisheries for their livelihood and because of the geographical dispersion of these fishing activities fish distribution is widespread.

Traditional small-scale fishing craft vary greatly in design but not in concept. They are manufactured from locally available materials and develop within the constraints of those materials. Until recent times, propulsion has been by paddle or sail generally with high levels of competence. Many small-scale fishing craft are beach based, launched and recovered by their crews.

Since the 1950s, mechanisation has been introduced almost universally and many changes have been seen in small-scale fisheries. Mechanisation has resulted in improvements in productivity, by increasing available fishing days, opening up new fishing grounds and in the introduction of more efficient fish catching methods.

Many canoe type small boats have benefitted from outboard motors and larger traditional craft have been fitted with diesel engines. In the era of abundant cheap fuel, mechanisation resulted in increased supplies of fish for human consumption at prices affordable by rural populations.

Rapid rises in fuel prices in the 1970s have threatened the economic viability of small-scale mechanised fishing vessels which are still operated on patterns established during the cheap fuel era.

2. RISING FUEL COSTS AND THEIR EFFECT ON SMALL MECHANISED FISHING CRAFT IN DEVELOPING COUNTRIES

Two major effects on the viability of artisanal fisheries have resulted from fuel energy cost increases. The first and most obvious is the direct rise in operational costs due to increased fuel and oil costs. At the same time the general recession caused by fuel costs increases has decreased the purchasing power of consumers in developing countries. This has put pressure on primary producers such as farmers and fishermen, not permitting the prices of primary products (including fish) to rise at a rate that will permit the increased operational costs to be passed on.

Secondly, the greatly increased foreign exchange requirement for the purchase of fuel oil and the higher prices charged for imported manufactured goods have caused such an imbalance in the external trade of many developing countries that they have difficulty in obtaining sufficient foreign exchange for the importation of even the most essential amounts of fuel oil and mechanical equipment. All of us are familiar with fuel cost increases in our own countries which affect us directly, for example gasoline cost about U.S.$ 0.30 per gallon in Florida in 1973, while now in 1983 the cost is about U.S.$ 1.10 per gallon. However, in many developing countries even higher price rises have occurred and for the reasons given above price increases cannot be passed on to the consumer. Therefore, fishermen have been forced to absorb the increased operating costs which over the period have reduced profitability, incentive and activity.

Some examples from FAO Sail Project experience indicate the gravity of the situation.

In Somalia, with per capita earnings of U.S.$ 180, gasoline is only available with Government permit for every litre bought at the pumps. Diesel is more easily obtainable at equivalent U.S.$ 2.20 per gallon (1982) but is of poor quality with many impurities. Engine spare parts for most small engines have been unobtainable for some years, except when supplied by aid organisations.

In Guinea Bissau (PCE$ 160), fuel is seldom available. Periods of two or three months without supplies for the fishermen are not uncommon. The price of gasoline is equivalent to U.S.$ 3.47 per gallon and diesel U.S.$ 1.69 per gallon.

In Sierra Leone fuel is generally in short supply. In recent months, the supply situation has deteriorated further and artisanal fishing activity has been severely reduced. Petrol prices of equivalent U.S.$ 2.7 per gallon already represent 70 percent of operating costs. This should be compared with the 1978 per capita earning of U.S.$ 182.

In Senegal (PCE$ 223) the small-scale beach fishery is very highly developed and supplies large quantities of fish to the rural population via a well organised artisanal distribution system. There are approximately 3 000 canoes operating on the coast, using modern fishing methods to meet ever increasing demands. Almost all canoes are outboard motor powered. The Government has subsidised the small-scale fishery by allowing fishermen to purchase fuel and outboard motors without the 60 percent tax paid by all other users. Even with this advantage, fuel costs of equivalent U.S.$ 1.20 per gallon represent 40 percent of operating costs. Without the subsidy, the operation of the motorised canoe fishery would not be viable.

The subsistence fishery in Madagascar continues to supply small quantities of fish to coastal villages using traditional sail powered outrigger canoes. Attempts to develop an artisanal fishery have been unsuccessful as operating costs of engines make the operation uneconomic.

In Indonesia, fuel prices to small-scale fishermen have increased by 300 percent from January 1982 to January 1983. Market forces have held the price of fish to within 30 percent of their 1979 level. There are many restrictions on industrial fishing operations to conserve fish stocks and encourage small-scale fisheries, but with present motorisation in certain parts of Indonesia the small-scale fishery is uneconomic.

At the present rate of decline, many artisanal and small-scale fisheries, which are already economically marginal, will severely reduce catching effort. Inevitably, the areas affected first are those with the most pressing need for improved diet - these areas are in danger of losing a large proportion of its fish catch as a valuable source of protein.

3. SOME SOLUTIONS TO THE PROBLEM

The task of reducing fuel costs in small-scale fisheries must be tackled on many fronts. This paper is primarily concerned with the use of sail power as a means of reducing fuel consumption and thus operating costs, but other avenues must also be pursued. Reference (1) lists five options which could be used singly or in combination:

1. Develop improved energy efficient engines and/or propelling devices.
2. Concentrate on reduction of hull resistance in the design of new fishing vessels.
3. Change fishing emphasis from high energy consuming fishing methods to those requiring lower energy inputs, e.g. a switch from stern-trawling to mechanized longline systems for high quality bottom fish stocks.
4. Reduce installed hp and operating speeds.
5. Use alternative energy sources, e.g. wind power.

3.1 Improved engines and propelling devices

Outboard motors used in small-scale fisheries are principally designed for the leisure market. These are lightly constructed, high revving, two cycle engines with intricate electrical systems, requiring a high level of maintenance and spare part replacement. They are not designed for commercial operation and in the prevailing conditions of artisanal fisheries in developing countries, have a useful life of one to two years. Fuel consumptions of the order of 0.7 lbs/hp hour and additional cost of 2 cycle oil, were not serious constraints during the time of cheap energy. Spare parts were readily available before restrictions on foreign exchange.

The convenience of outboard motors is such that they will never be completely replaced. The technology exists, however, to produce engines suitable for small-scale fishing operations, with long life, good specific fuel consumption, and the durability necessary to survive in working conditions.

An alternative to the outboard is the small air cooled diesel engine which is more fuel efficient and durable than present outboards. Problems such as higher initial expenditure, increased weight, protection of an engine against swamping in beach landing craft and the difficulty of fitting propeller and sterngear for these conditions can be overcome. One FAO project in the Bay of Bengal is gaining acceptance for an inexpensive low hp engine of this type totally enclosed in a pivoting engine box with incorporated sterngear, propeller and rudder which can realise fuel economies of the order of 50 percent over the equivalent outboard powered craft.

3.2 Rationalisation of Power Requirements According to Fishing Method

With cheap and abundant fuel there was little incentive to carry out careful matching of engines, sterngear and propeller, while the tendency to increase horsepower progressively to the point where up to 30-40 percent increases in fuel consumption resulted in speed increases measured in fractions of a knot.

Considerable attention is being paid in a number of FAO fisheries projects in developing countries to this problem and it would appear that the most immediate results in fuel saving can be expected from a combination of choices 4 and 5 in the options listed above.

Probably the most significant fuel saving in small fishing craft can be achieved by a reduction in operating speed, i.e. a reduction in utilized Shp/ton of displacement, (always provided that an appropriate propeller is fitted for the reduced operating hp and rpm). Recent fuel consumption trials of an 8.7 m (28 ft 6 in) inshore fishing craft with a 30 Bhp engine indicated that a one knot reduction in speed from 7 to 6 knots for this craft resulted in a reduction from 6 hp utilised ton of displacement of 2.6 and a reduction in fuel consumption of about 30 percent. Actual fuel consumption in litres/hour dropping from 6.5 to 2.4. While this sort of saving can be expected in small craft operating near their maximum hull speed, such savings in fuel costs do not take account of the cost of increased voyage time, possible reduction in fish prices for later arrival in port, nor the human reaction of a fisherman not wishing to see his contemporaries pass him at a knot better operating speed.

3.3 The use of Sail

One solution to this latter problem is the use of combined sail and engine power to produce equivalent speeds at substantial fuel saving.

For this particular vessel it was possible to demonstrate that the use of 24 m^2 of sail in a 15 knot true wind using 65 percent rpm (approximately 60 percent of maximum continuous Bhp) gave an operating speed of 7 knots at an apparent wind angle of 90^{o} and 6.5 knots at an angle of 50^{o}, see Fig. 1. From this figure it can be seen that at an average operating speed of 6.5 knots fuel consumption in litres/hour is 3.8 l/h under engine alone, 2.4 l/h using reduced engine power plus sail at a course angle of 50^{0} to the apparent wind (close hauled) and 1.25 l/h at an angle of 90^{0} to the apparent wind (reaching).

Until the turn of the century, all ocean transport was sail powered so it is natural for the reintroduction of sail as a means of propulsion to be considered to reduce fuel consumption. At the end of the era of sail, vessels, techniques, and specialisation were very highly developed, even though industrial technology was relatively primitive. In the industrialised countries since the coming of steam until very recently, sail development has been confined to recreational craft. Most of the traditional skills for handling transport ships and fishing vessels under sail have been lost.

In the developing world too, sailing as a means of propulsion for fishing craft has declined in recent years and is under-utilised in many areas despite favourable winds. In some areas such as the northeast Indian Ocean, the China Sea and Malaysia, sea-faring populations have developed sailing methods and use sail for much of the time. However, large parts of Africa, Indonesia, and Central and South America, have not developed sails for their craft through lack of suitable materials, information and motivation.

Wind patterns between the tropics are generally stable and predictable with large areas benefitting from regular trade winds. In areas where sailing has been developed, suitable combinations of hull and rig were evolved. However, their development is considerably less advanced than the sophistication achieved by the North European and American sailing fishing fleets in the early 20th century.

Some reasons for the lack of continued development in developing nations are not hard to find. Many of the hulls are not strong enough to take the strains imposed by a tall sailing rig. Materials suitable for making efficient sails have only recently become available with the increasing use of machines to weave local cottons tightly enough to be if adequate density and strength. Many countries do not have suitable trees for long, straight spars, so that sailing rigs with short masts and spars made up of several pieces lashed to form a long length have evolved.

Specialists working in the field of sail development have the advantage of an overview of rigs and techniques on a world wide basis plus experience of modern materials and technology. This enables a new approach to the design of sailing equipment for a traditional fishery within the economic and geographical constraints of the region. Ideally, this means using locally available materials in existing craft, even though some of the materials may not have been used before for sailing (e.g. galvanised wire rope). The economy of the fishery may justify importing some items such as fastenings, or nylon thread, which, although of minor importance in total cost can make surprising improvements in the efficiency of the vessel and rig.

The aim must be to develop an acceptable appropriate sailing system which causes worthwhile fuel savings and which is sufficiently convenient and inexpensive for the fisherman to adopt spontaneously.

Many artisanal fishing craft will sail without serious alterations. Almost any hull will run before the wind or broad reach. Most hulls will beam reach without appreciable leeway. To sail to windward requires a hull form with reasonably fine underwater lines and adequate lateral plane. In some small craft, this can be achieved by the addition of leeboards or centre boards.

A study of the fishery context in which a craft is operating, its hull form, and materials locally available for rig manufacture, will enable an appropriate sailing rig to be designed.

In some cases, it will be possible to design an sailing rig as primary propulsion. More often, the rig will be auxiliary, particularly when passages to windward are required. When motor sailing to windward, the lift coefficient of the hull and appendages is not critical as the engine can provide much of the necessary windward component.

In all cases, the use of engines will be necessary to maintain production levels. Project experience has shown that fishing under sail alone rarely allows the same level of effort as achieved in the time of cheap fuel. As can be seen from Fig. 1, the most significant contribution of appropriate, locally produced sailing rigs is in the context of motor sailing, where reductions in engine hours up to

50 percent have been recorded whilst maintaining previous levels of fishing achievement.

4. SAILING RIGS FOR SMALL FISHING CRAFT

4.1 Requirements of a Sailing Rig

Appropriate rigs should:

- Be constructed from materials which are locally available or can reasonably be obtained.
- Be convenient and easy to handle, and not obstruct fishing operations.
- Be easily and effectively reefed so that fishing operations can be carried out in varying weather conditions.
- Be capable of working close to the wind, as when motor sailing in light airs, the apparent wind direction will be within 45^{0} of ahead up to 50 percent of the time.
- The propulsive efficiency of the rig should be demonstrably high enough to be attractive to fishermen, whilst ensuring the maximum possible safety for the vessel.
- For surf and open beach landing, the rig must be suitable for stepping and unshipping at sea.

4.2 Project Experience

The Food and Agriculture Organization of the United Nations has organised a number of Sail Projects in African countries. Some of these projects carried out by the Fisheries Technology Service of FAO in collaboration with MacAlister Elliott and Partners have been and are demonstrating the manufacture and installation of appropriate sailing rigs from locally available materials. This experience has been added to by other projects in which MacAlister Elliott and Partners have installed sailing rigs and introduced improved boatbuilding methods.

Tailors and local artisans have been trained in the techniques of making improved sails, and the use of synthetic fibre ropes and wire for running and standing rigging.

The completed sailing rigs have been demonstrated to fishermen in authentic fishing conditions; alterations in fishing methods, if required, have been identified and introduced.

The aim of these projects is to assist small-scale fishermen to develop sailing rigs from their own resources, which are suitable for their fishing methods and will contribute to the propulsion of their craft.

Many small-scale fishing communities have developed their fishery beyond recognition of the fishing practices of past generations. The mobility of motorisation has given a degree of independence from the previous restrictions of currents and wind. In many cases, a generation has grown up without the knowledge of seamanship required to operate fishing craft under sail and the skills have been lost.

The urge for speed and increasing amounts of horsepower is a very natural human reaction and it is often difficult to promote sail as it is considered retrogressive.

Project experience, however, has shown that in countries where fuel has become unavailable for long periods and effort has been severely curtailed, fishermen are frequently willing to learn and to apply the seamanship required to sail their craft.

On the other hand, in countries where fishing with engine power is still possible, no matter how rapid the decline in profitability in recent years, fishermen resist efforts to introduce primary or auxiliary sailing systems.

The efficiency and convenience of the rig and motor/sail balance is therefore critical for acceptance.

To assist with acceptance, programmes of training fishermen in the use of sailing rigs are proposed. Early experience of this work has been encouraging - fishermen making continuous use of sailing rigs in Cacheu in northern Guinea Bissau have convinced their colleagues of the benefits by example. Initial education was necessary to demonstrate the techniques of utilising the sailing rigs to best advantage.

5. DESCRIPTIONS OF RIGS USED IN DEVELOPMENT PROJECTS

5.1 Gaff Rig

The gaff rig was much used by fishing craft on both sides of the Atlantic until the late 1920s. The gaff schooner developed on the American eastern seaboard. The schooner configuration was popular for its windward ability in bringing to market, against the prevailing westerlies, fish caught on the Grand Banks. In European waters, the ketch and cutter rigs were more common, markets being generally to leeward of fishing grounds.

The gaff rig was introduced in an FAO project to replace the lateen rig on the Mashua type fishing craft in Southern Somalia. Many Mashua's were motorised and their sailing rigs had fallen into disuse. Fishing methods are predominantly gillnetting and handlining. The traditional lateen sail's primary disadvantages are the lack of reefing ability and the large crew required to handle the yard when setting or lowering sail, and manoeuvring.

The gaff cutter rig designed has a loose footed mainsail, jib set on the end of a bowsprit and staysail set on the forestay. There is provision for a light weather topsail. The overall sail area is similar to the original lateen and is manageable by one man. Reefing is easily accomplished, keeping a reasonably efficient sail shape for windward sailing when deep reefed, Figs. 2 and 4.

The gaff mainsail is not as efficient to windward as sails with a relatively longer luff (leading edge) but for reaching and running, the rig spreads a large effective sail area.

The gaff cutter rig was also introduced to the 5.8 m (19 ft) fishing craft on Lake Malawi. These craft are used by artisanal fishermen for gill and circle netting. The rig is used as primary propulsion, with outboard motors for use in windless weather, Fig. 3.

5.2 Sprit Rig

The sprit was commonly used by both small fishing craft and cargo vessels up to 20 m LOA in Northern European waters. The sail has a similar configuration to the gaff sail but is spread by a standing spar secured at the base of the mast, Fig. 5. The sail is normally gathered to the mast for stowing, Fig. 6.

The sprit rig was introduced for use on the 8 m GRP motor fishing craft in Somalia, Figs. 7 and 9. These boats are mainly used for gillnetting and longlining. They are fitted with deck houses above the engine space which restricts space on deck. Whilst setting and hauling fishing gear, the rig is unobstrusive.

The rig is easily handled by one man with proper running gear, and sets a large sail area when reaching or running. The sprit is necessarily a long spare and is required to be as light as possible.

The set of the sail, particularly to windward, is dependent on the stiffness of the sprit. Suitable long, straight and stiff spar material is not available in many countries.

The traditional canoe fishery in Senegal used a type of sprit rig for inshore fishing and river transport. The rig fell into disuse with the introduction of outboard engines. However, the smallest of the beach canoes still use the sprit rig. A study of their economic situation relative to the larger motorised canoes shows a profitable operation, whereas the profitability of the motorised canoes has declined. The sprit sail as set in Senegal could be considerably improved by the use of man-made fibre twine in sail making. Sails presently in use are of poor aerodynamic shape with over-stretched leach (rear edge) panels so that beating to windward is difficult or impossible. With elementary skills of sailmaking, these problems could be solved and the efficiency of the sails greatly improved.

5.3 Lug Sails

5.3.1 Chinese type, fully battened lug sail

The junk sail is still in widespread use in Southeast Asia, where it has been the primary propulsion method for all types of craft for more than a thousand years. In recent times, the junk type of fully battened lug sail has been used in other areas and with modern materials. These rigs have demonstrated the advantages of multi-part sheets spreading rig stress and quick, efficient reefing.

The junk rig forms the sail shape and holds it rigidly with the full length battens. Thus, inferior sail material may be utilised.

The junk rig was introduced in Somalia for the 6.4 m GRP coastal fishing craft, Figs. 8 and 10. These craft have small inboard diesel engines and are used for handlining and gillnetting. When reaching or running the rig gives similar speeds under sail to those achieved under power and performs reasonably to windward using a lee board. The flat shape of the fully battened sail is particularly efficient for motor sailing. The Indian Ocean coast of Somalia experiences varied wind strengths in different seasons, ranging from light airs to near gale force at the height of the Southeast Monsoon. The junk rig allows the setting of the required amount of sail for the daily conditions and swift effective reefing.

The junk rig has also been introduced in a Sail Development Project in Guinea Bissau for the larger (12-15 m) fishing canoes. The canoe hull is fine lined and easily driven, with a pronounced rocker to the hull shape which provides some stability when heeled. The junk sail stows in its lazy jacks during fishing operations; nets are handled aft of the beam or forward of the mast with the fish hold being positioned under the stowed sail. The rig is not suitable for canoes operating from a surf beach as the running rigging is too complex for rapid unshipping at sea which is necessary for passing through the surf.

5.3.2 Dipping lug

The lug sail, in its various forms, was the most widely used sailing rig amongst the small-scale fishermen in European waters before mechanisation. Dipping and standing lug sails are variations of the same principle of a yard headed, quadrilateral sail.

The dipping lug is set on an unstayed mast, the halyard being set up on the windward gunwhale so that with the tack of the sail secured at the stem head, the rig is well supported. The dipping lug is an efficient sail shape for all points of sailing but has the disadvantage of having to be lowered and re-hoisted on the other side when tacking, hence its name. The sail is set without a boom and with simple running rigging, reefing is effective and simple.

The dipping lug was introduced on Lake Malawi for the 4.5 m (15 ft) outboard powered fishing craft. In the largely stable wind conditions of the lake, the sailing performance of the rig is satisfactory for primary propulsion.

5.3.3 Standing lug

The standing lug sail is tacked at the mast so that the rig is self-tending when going about. The sail is normally set with a boom, and the mast set up with standing rigging.

In small craft such as the 7 m GRP canoe in Somalia, Fig. 11., the standing lug rig is set on an unstayed mast and used without a jib. The canoe was designed to carry an inboard diesel engine and has sufficient lateral plane for beating to windward without excessive lee-way. Fishing methods carried out from the canoe are handlining and diving for crustacea. The boom and yard do not intrude when stowed in the boat.

For the heavier displacement craft of 7.6 m in Northern Lake Malawi, Fig. 12, the standing lug is used on a stayed mast and a jib is set when beating to windward. Points reefing is effective and reasonably simple.

The standing lug has also been introduced for the beach canoes in Guinea Bissau and Sierra Leone, Figs. 13 and 14, where raw materials for sailing rig construction are scarce. However, trees can be found of adequate strength for the relatively short masts of this rig and bamboo is often available for spars.

5.4 Gunter Rig

This is similar in configuration to the Bermuda or Marconi rig, which is seldom considered appropriate in developing nations in view of the sophisticated mast, fittings and sail cutting required.

The gunter rig uses a yard in the same way as the gaff and lug rigs but the yard is set vertically above a relatively short mast. This rig is suitable for light displacement craft and is efficient for close hauled sailing.

The gunter rig has been introduced in the Bijagos Islands in Guinea Bissau fishing canoes. Results have been encouraging with good performance though the rig has proved closer-winded than the hull is capable of due to leeway. However, motor sailing allows good progress to windward with minimal fuel use.

Another use of a gunter rig for a beach landing craft in India is shown in Fig. 15.

5.5 Lateen Rig

The lateen rig (name derived in English from the rig used by Latin seafarers) in the configuration widely used in African and Asian countries, originated in the Arab world. The lateen is the first development from the square sail, and is still used in square sail fashion when running before the wind. In many small-scale fishing communtiies in East Africa and the Arabian Gulf nations, no other type of sail has been developed.

The lateen sail is set on a long yard, usually made up of a number of shorter pieces lashed together. The mast is relatively short, with removeable rigging to allow for changing the yard from one side to the other. In the larger sizes, manoeuvring under sail is complicated and requires large crews; reefing is difficult to accomplish and results in an efficient sail shape, particularly for windward work. The lateen sail shape when fully set on stiff spars is efficient on all points of sailing.

A lateen rig was introduced to the 6.5 m GRP motor fishing vessels in Somalia, Fig. 16. Another vessel of the same class was fitted with a sprit rig of the same area and comparative trials conducted. The speeds under sail of the two rigs is comparable for reaching and running. The lateen rig is superior for working to windward but has the disadvantage of interfering with the fishing methods with its complex running rigging, and requiring more crew to handle it.

The Jehazi of the Kenya coast, Fig. 17, have used the same lateen rig for generations. By improving the material used in sail making, stiffening the spar, and organising running rigging with turning blocks, the problems of handling the rig can be reduced and performance improved. With improvements in hull construction to absorb the point loads imposed by the rig and prevent leakage, better windward performance became possible.

6. CONCLUSIONS

Many subsistence and artisanal fisheries would benefit from the introduction of appropriate sailing rigs, either for primary or auxiliary propulsion. However, as has been pointed out, in some situations the introduction of sailing rigs would not be justified and fuel saving efforts should centre on improving the efficiency of mechanical power installed and in its intelligent use by operators.

The introduction of sailing rigs to a fishery requires careful study and design work, followed by technical assistance to train artisans in the skills of sailing rig construction; boatbuilders in the techniques of installing sailing rigs and the necessary construction improvements; and fishermen to use the rigs to best advantage.

Experience to date has shown that these principles can reactivate fishing effort in economically deprived fishing communities.

Efforts must continue to devise appropriate and acceptable sailing rigs for developing countries and train fishermen in their use.

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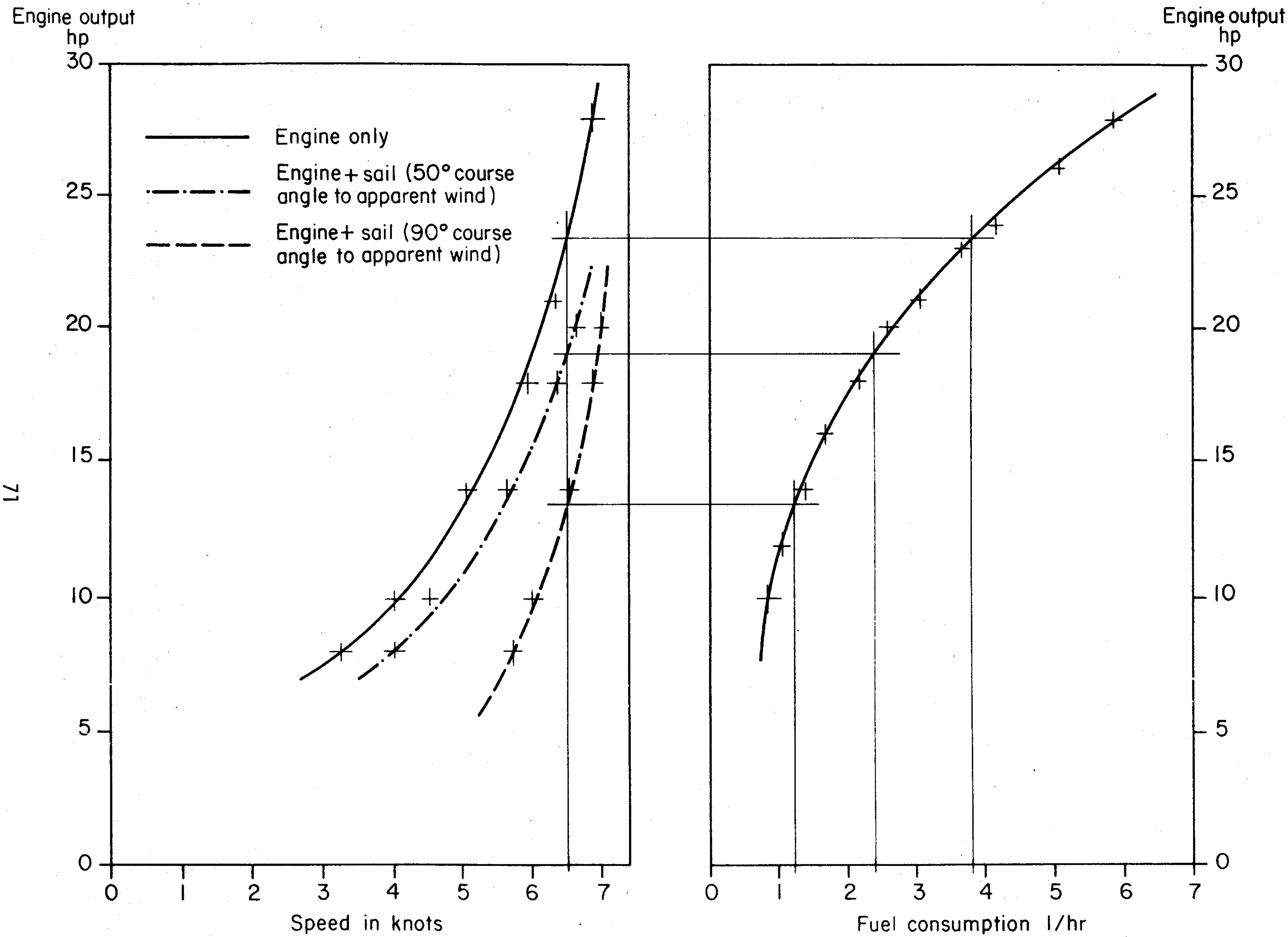


Fig. 1. Estimation of fuel consumption using various combinations of engine and sail power for an 8.5 m (28 ft) fishing boat in Somalia

Fig. 2. Gaff rig as a replacement for lateen rig on a traditional Mashua

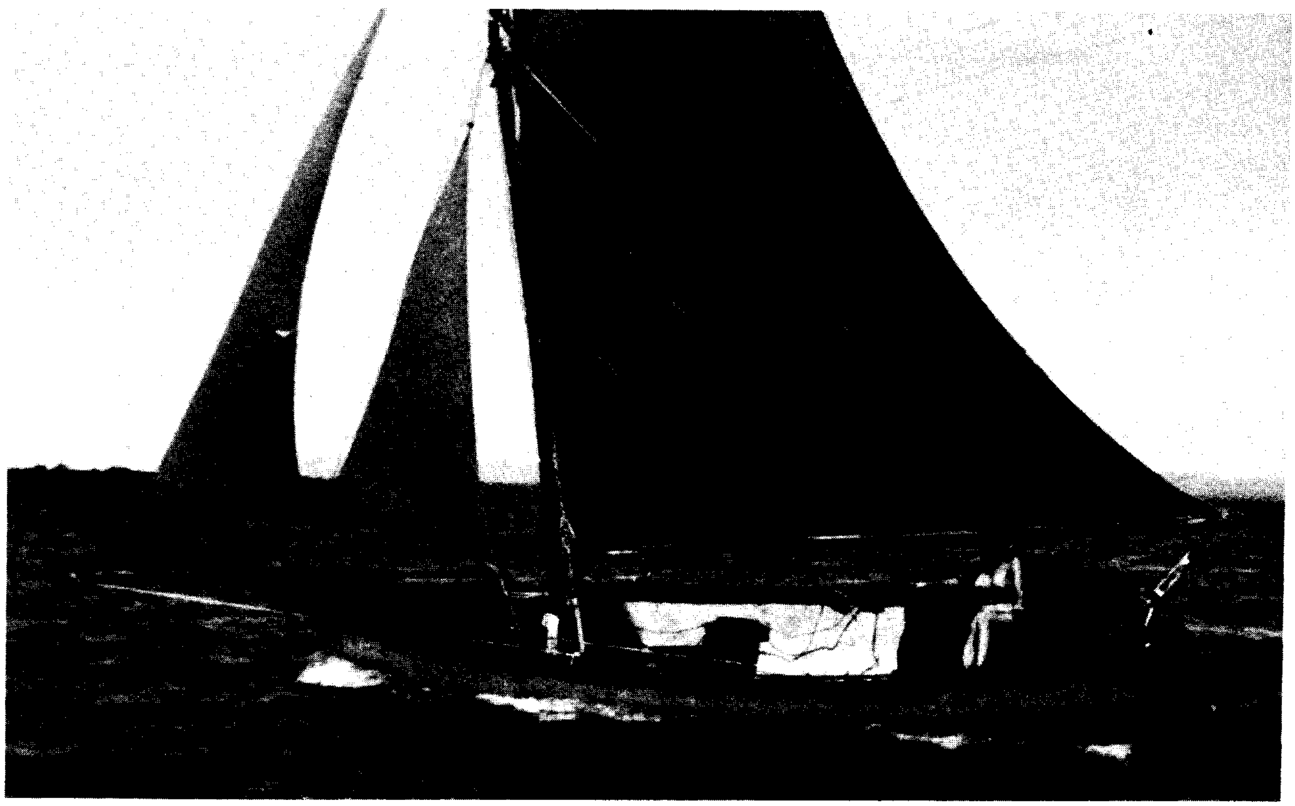


Fig. 3. Gaff rig on a 5.8 m (19 ft) fishing boat on Lake Malawi

MAIN PARTICULARS

Length over all	7.80 m	(25 ft 7 in)
Length water line	7.65 m	(25 ft 1 in)
Beam maximum	2.20 m	(7 ft 0 in)
Depth (approx.)	0.80 m	(2 ft 7 in)
Displacement light (approx)	2,500 kg	(5,500 lb)
Sail area (total)	25.07 m^2	(270 ft^2)

1. Gaff, length 4.50 m, diameter 60 mm
2. Peak halyard
3. Mast, length 9.40, maximum diameter 100 mm
4. Cross trees
5. Throat halyard
6. Gaff jaws around mast
7. Jib, area 3.64 m^2 (39 ft^2)
8. Jib outhaul
9. Bowsprit
10. Jib sheets
11. Staysail, area 5.25 m^2 (57 ft^2)
12. Top mast shroud
13. Mainsail down haul
14. Staysail sheet
15. Main shroud
16. Main sheet
17. Loose footed mainsail, area 16.18 m^2 (174 ft^2)

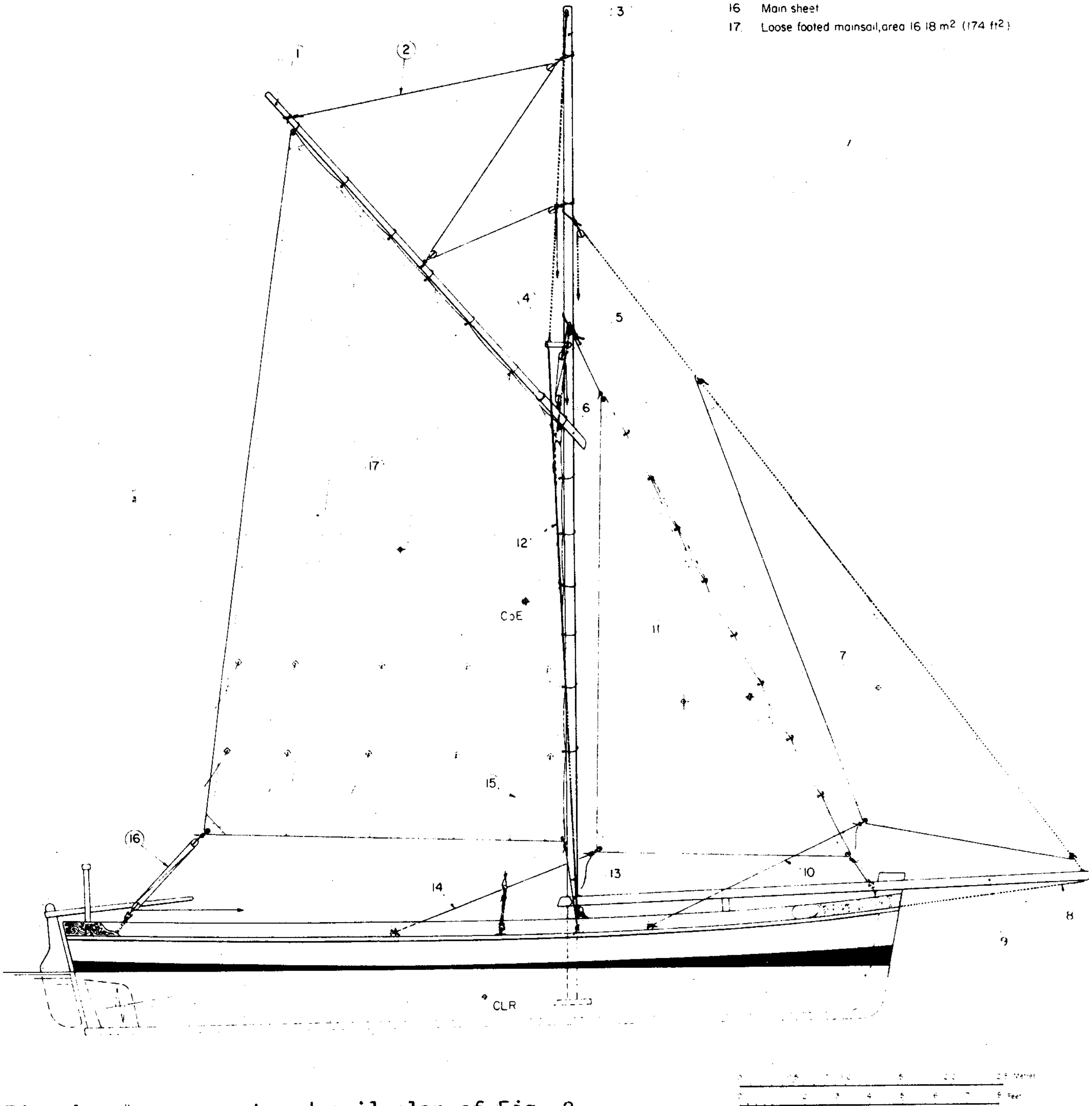


Fig. 4. Arrangement and sail plan of Fig. 2.

FAO	7.80 m Local Mashua
	EXPERIMENTAL GAFF RIG
Rig design SA	SOM/77-1
	1

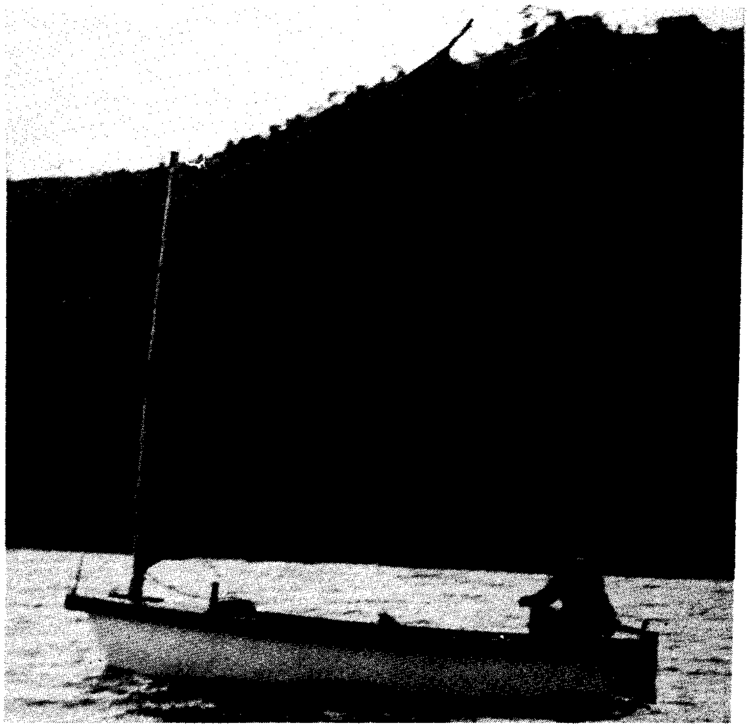


Fig. 5. Simple sprit rig on a 4.5 m (15 ft) Fishing boat on Lake Malawi

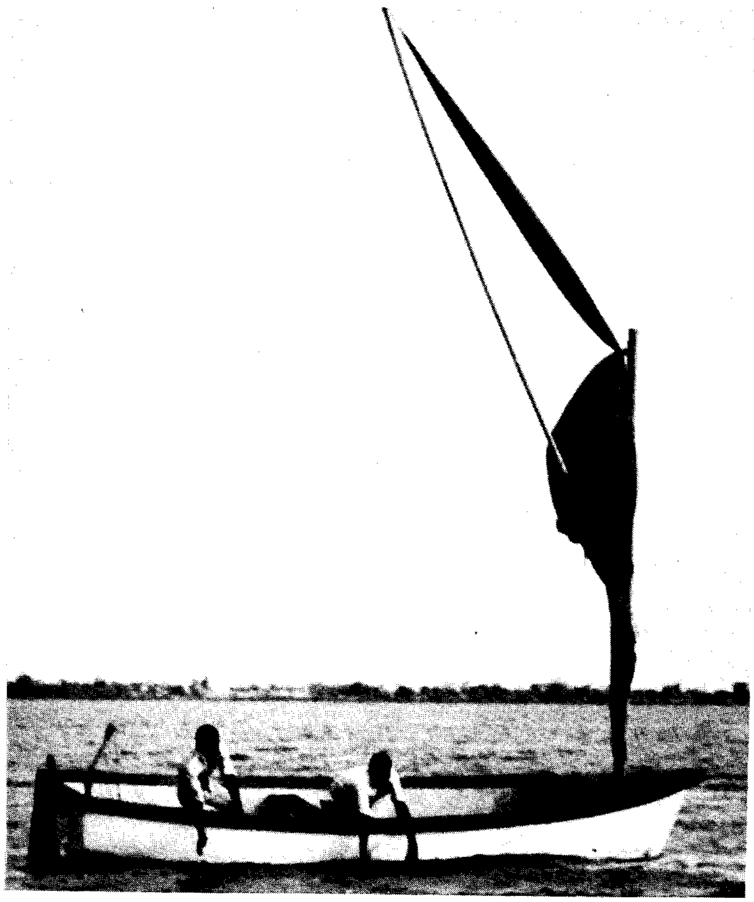


Fig. 6. Sprit sail brailed to mast leaving clear working area for fishing operations

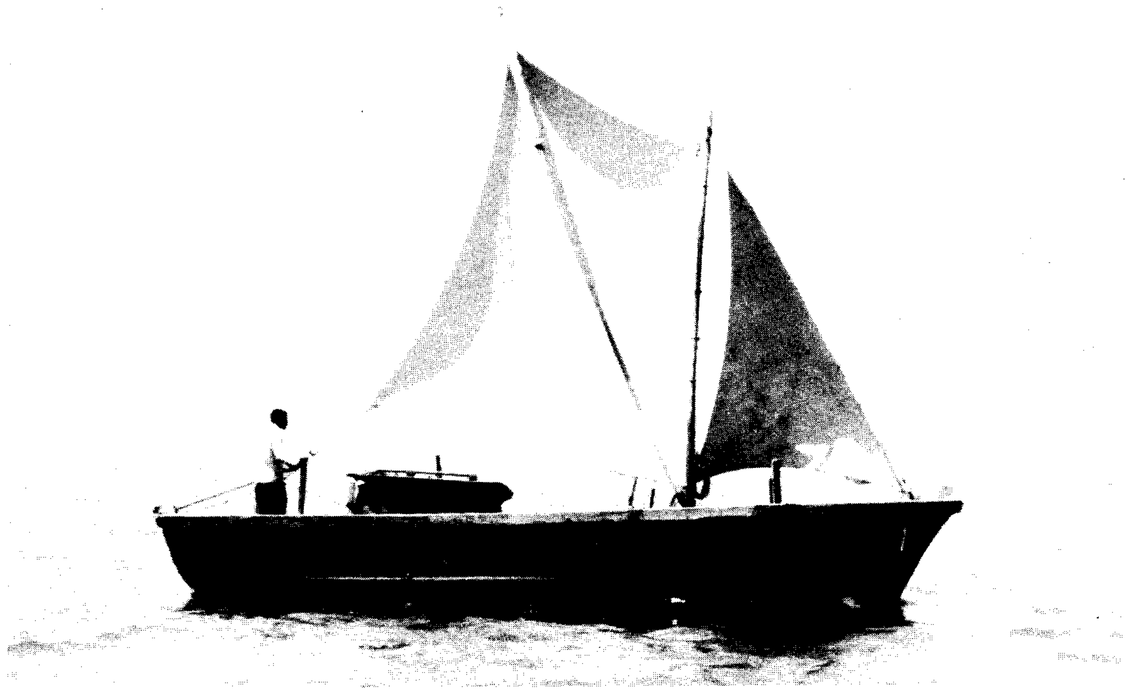


Fig. 7. 8.5 m (28 ft) fishing boat with sprit sail rig in Somalia

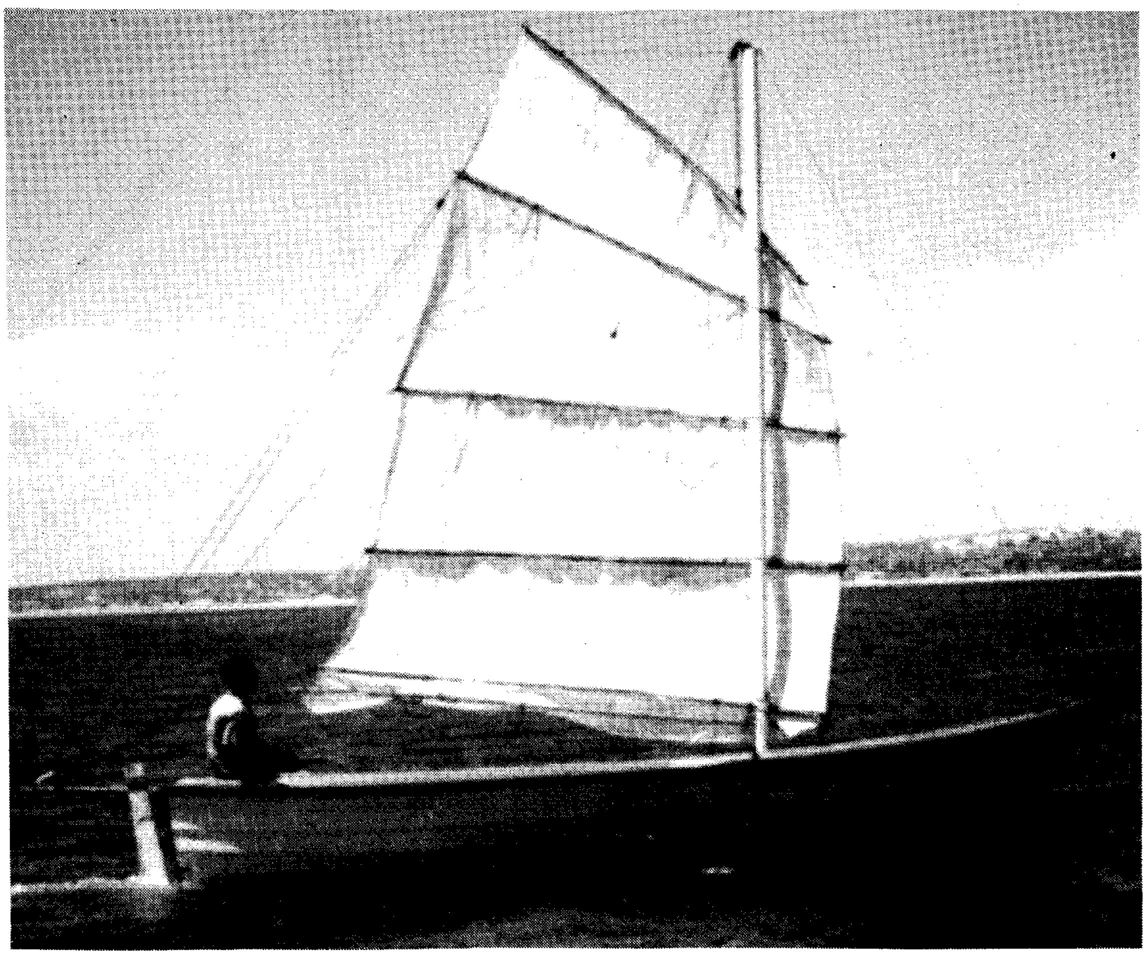


Fig. 8. Chinese type fully battened lug sail (reefed one batten) on a 6.4 (22 ft) boat in Somalia

MAIN PARTICULARS		
Length over all	8.70 m	(28 ft 6 in)
Length water line	7 50 m	(24 ft 7 in)
Beam maximum	2.65 m	(8 ft 8 in)
Depth (approx.)	1 10 m	(3 ft 7 in)
Displacement light (approx)	3,000 kg	(6,600 lb)
Engine	30 hp	
Sail area (total)	24 54 m^2	(264 ft^2)

1. Wooden sprit length 7 80m, maximum diameter 120 mm
2. Sprit topping lift
3. Spritsail peak halyard
4. Spritsail, area 19.50 m^2 (210 ft^2)
5. Spritsail throat halyard
6. Mast length from deck 5 50m, greatest diameter 120 mm
7. Jib halyard
8. Jib area 5 04 m^2 (54 ft^2)
9. Pipe bowsprit
10. Strop for raising and lowering the sprit
11. Jib sheets
12. Side stay in 6 mm stainless steel wire
13. Brailing lines for sail reduction
14. Main sheet
15. Rope main sheet traveller
16. Aft guy for sprit control

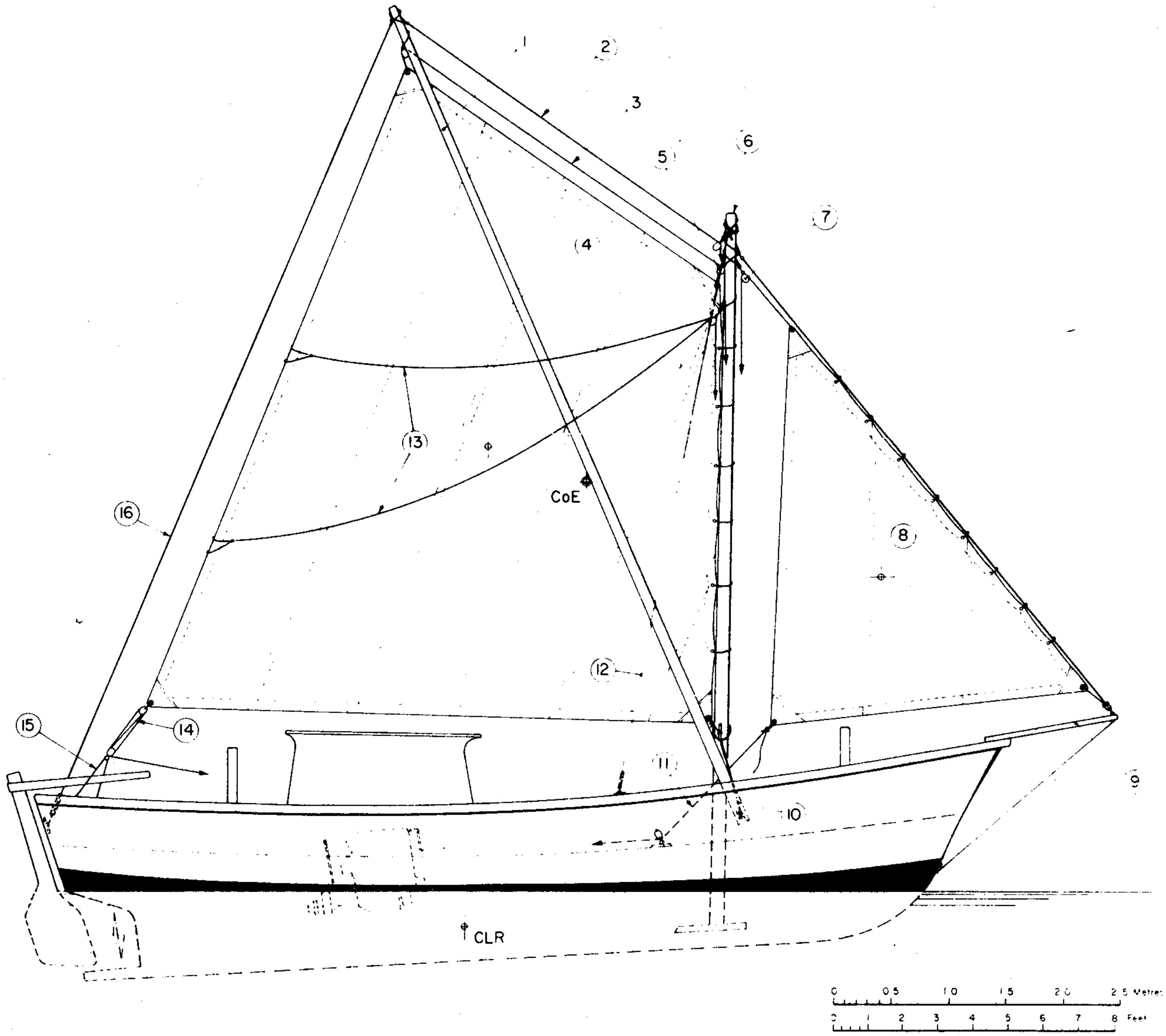
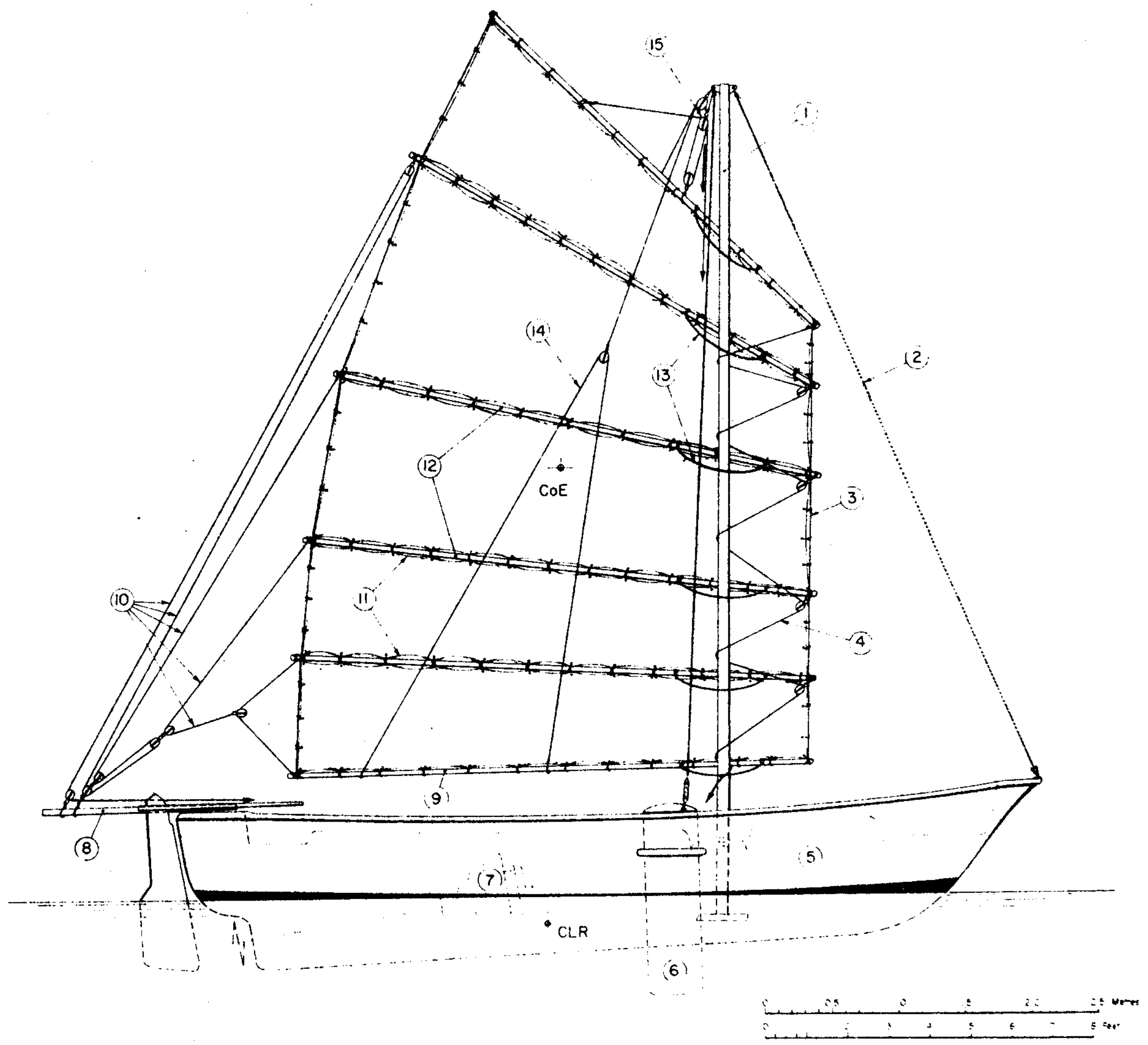


Fig. 9. Arrangement and sail plan of Fig. 7.

FAO	8.70 m FRP Fishing Boat (Sri Lanka)		
	EXPERIMENTAL SPRIT SAIL RIG		
	Scale as shown	Project No	Drwg No
	Rig design SA/JF	SOM/77-1	1
	Rome, Mars 1982		

MAIN PARTICULARS		
Length over all	6.40 m	(21 ft 0 in)
Length water line	5.40 m	(18 ft 0 in)
Beam maximum	2.20 m	(7 ft 0 in)
Depth (approx.)	1.00 m	(3 ft 3 in)
Displacement light (approx.)	1,000 kg	(2,200 lb)
Engine	6 - 7 hp	
Sail area	16.20 m^2	(174 ft^2)

1. Aluminium mast tube - stock item supplied with boat
2. Standing rigging 4 mm SS wire only necessary with aluminium mast
3. Roped luff and leech of sail panels
4. Mast inhaul used to move the position of the centre of effort of the sail fore and aft
5. 6.40 m FRP hull
6. Lee board changed from port to starboard as required
7. 7 hp diesel inboard engine
8. Wooden bumpkin to lead the main sheet fair of the sail
9. Boom, of similar dimensions to sail battens in small craft
10. Multiple main sheet attatched to each batten
11. Individual sail panels lashed to the battens
12. Full length sail battens
13. Parrel lines holding individual battens to the mast
14. Multiple topping lifts both sides of sail
15. Mail halyard with purchase



6.40 m FRP Open Fishing Boat		
EXPERIMENTAL SAIL RIG		
Scale as shown	Project No.	Drwg No
Rig design JF/SA	SOM/77-1	1
Rome, Mar 1982		

Fig. 10. Arrangement and sail plan of Fig. 8.

MAIN PARTICULARS

Length over all	7.00 m	(23 ft 0 in)
Length water line	6.20 m	(20 ft 4 in)
Beam maximum	1.30 m	(4 ft 3 in)
Depth (approx.)	0.80 m	(2 ft 7 in)
Displacement light (approx.)	700 kg	(1,540 lb)
Sail area	11.33 m²	(122 ft²)

1. Lug sail yard, length 3.80 m
2. Standing lug sail, area 11.33 m²
3. Main halyard purchase
4. Aluminium mast, length 6.00 m as supplied for 6.40 m swedish boats
5. Rope parrel holding yard to mast
6. Rope parrel holding boom to mast
7. Tack pendant
8. Boom preventer
9. Loose foot of sail fastened to the boom at tack and clew only
10. Boom, length 3.40 m
11. Main sheet purchase
12. Rope horse for main sheet
13. Reef points

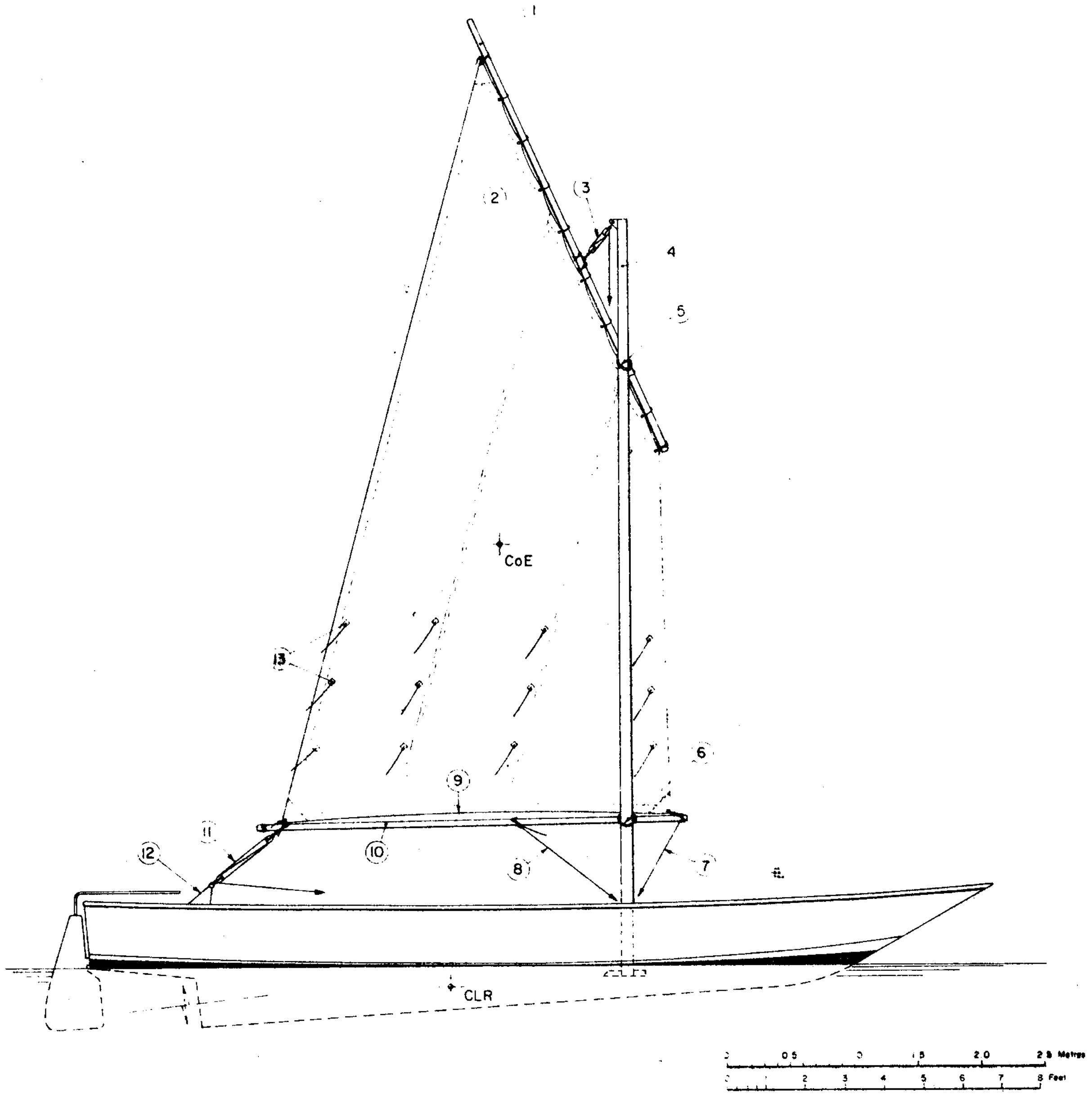


Fig. 11. Standing lug rig on a 7 m (23 ft 6 in) canoe in Somalia

7.00 m FRP Canoe (Kenya)		
EXPERIMENTAL STANDING LUG RIG		
Scale as shown	Project No	Drwg No.
Rig design SA Rome, Mars 1982	SOM/77-1	1

Fig. 12. 5 m (17 ft) fishing boat using a standing lug on northern Lake Malawi

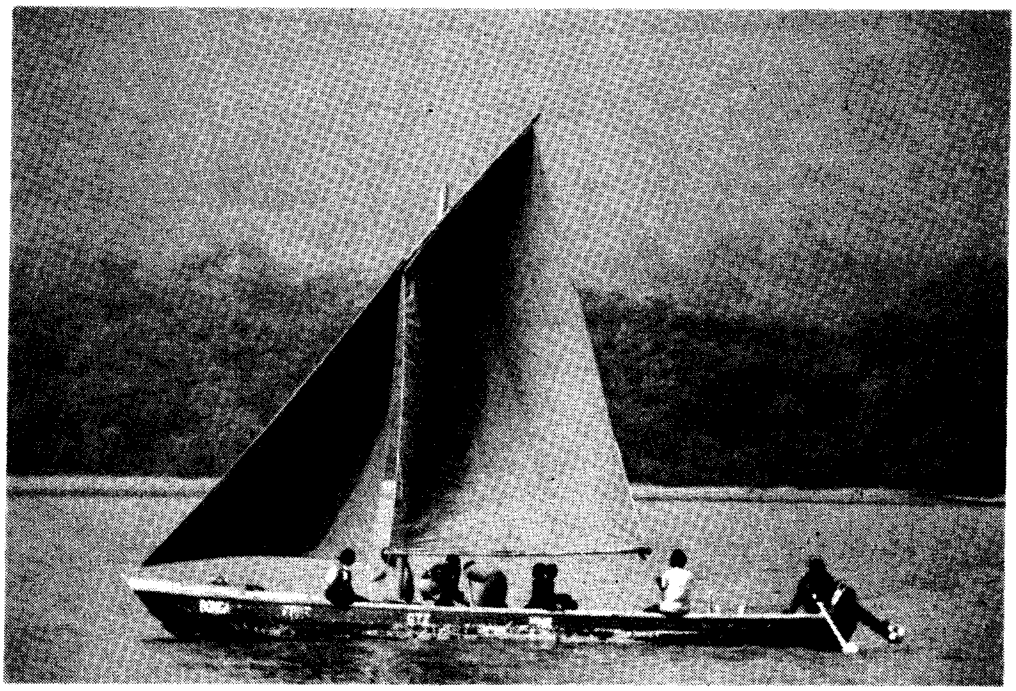


Fig. 13. A standing lug rig used on an 11 m (36 ft) canoe in Sierra Leone

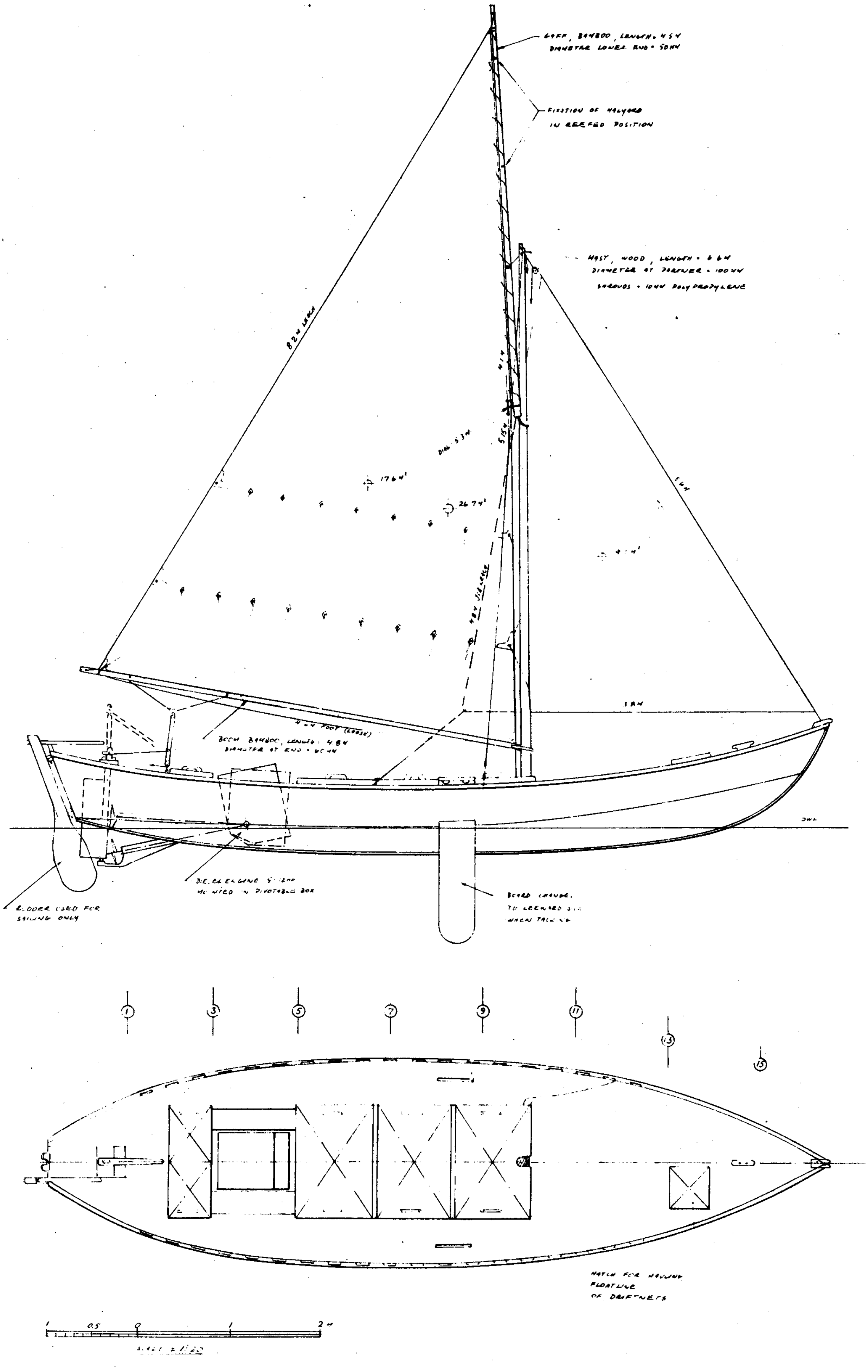


Fig. 15. A gunter rig used on an 8.4 m (28 ft) beach landing craft in India.

Fig. 14. View of the rig fitted to the canoe of Fig. 13

MAIN PARTICULARS

Length over all	8.70 m	(28 ft 6 in)
Length water line	7.50 m	(24 ft 7 in)
Beam maximum	2.65 m	(8 ft 8 in)
Depth (approx.)	1.10 m	(3 ft 7 in)
Displacement light (approx.)	3,000 kg	(6,600 lb)
Engine	30 hp	
Sail area	20.80 m^2	(224 ft^2)

1. Upper yard extension
2. Wooden yard 75 mm diameter
3. Wooden reinforcement for yard - central section
4. Mast length from deck 5.20 m, maximum diameter 120 mm
5. Sheave hole at masthead for halyard
6. Lower yard extension
7. Lower yard guys
8. Bamboo "bowsprit" for yard lead
9. Rope halyard led to windward
10. Mast support stay led to windward
11. Sheet
12. Upper guy for control of yard

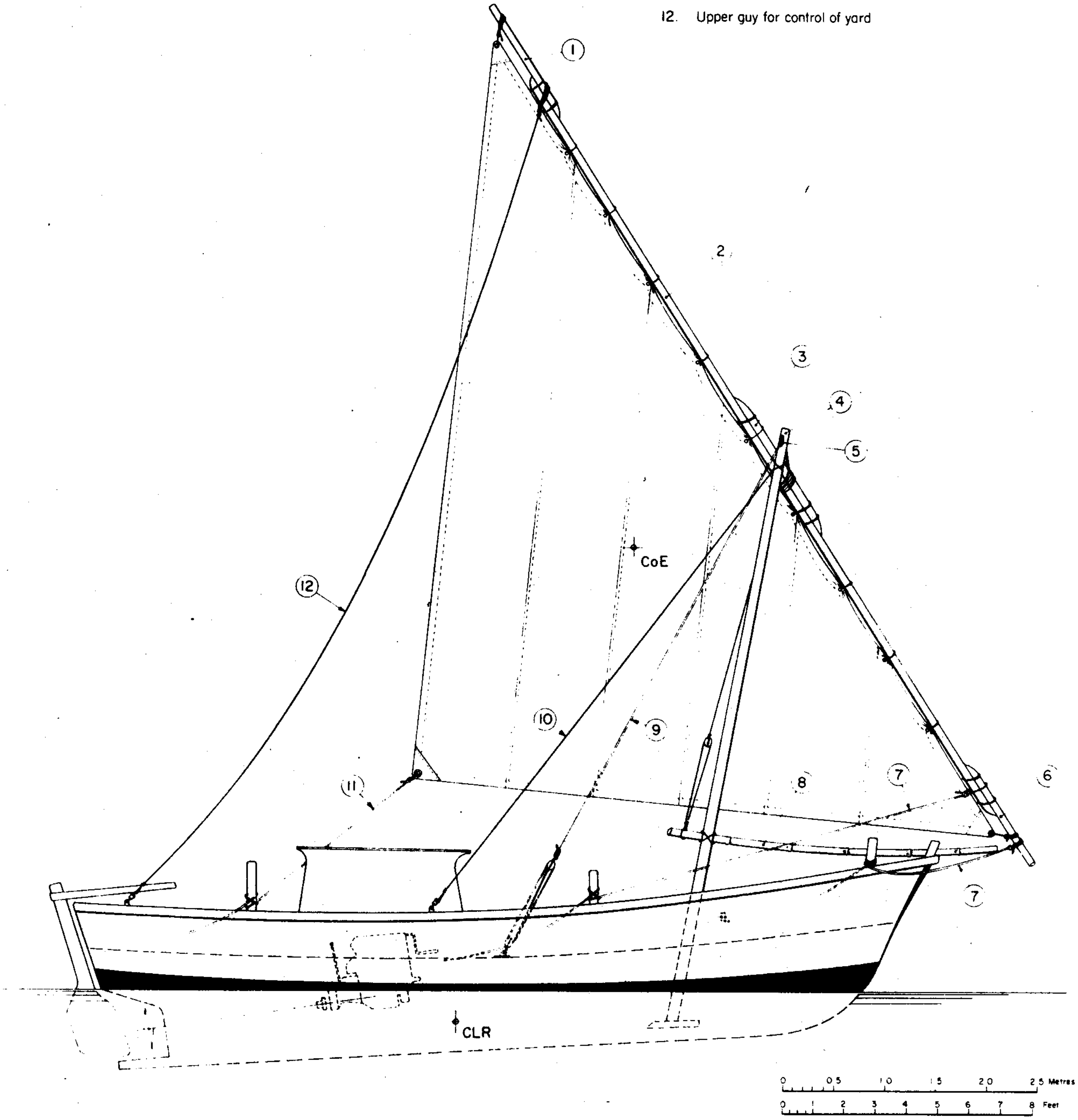


Fig. 16. Lateen rig fitted to the same hull as that of Fig. 9.

8.70m FRP Fishing Boat (Sri Lanka)
EXPERIMENTAL LATEEN RIG

Scale as shown	Project No	Drwg No
Rig drawn by J.F.SA	SOM/77-1	1
Rome, Mars 1982		

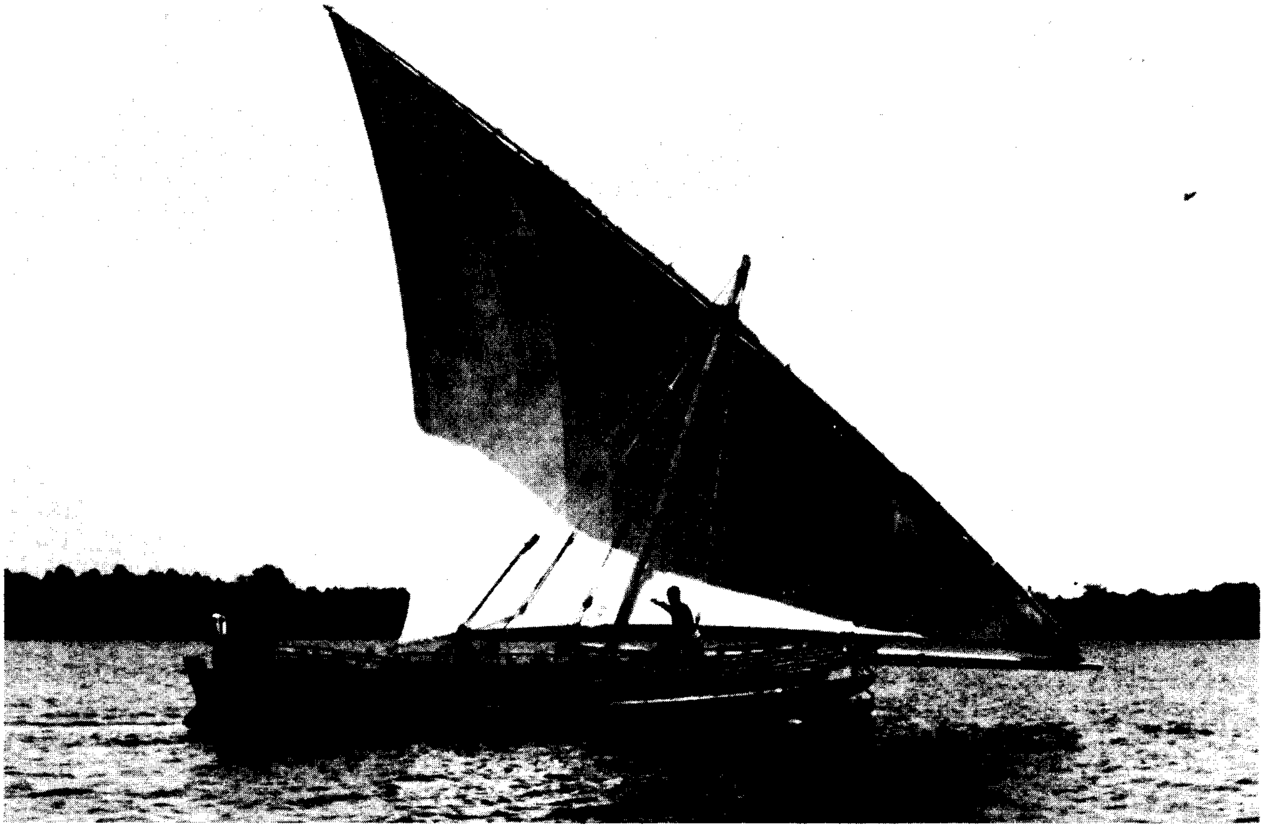


Fig. 17. A typical Kenyan unmotorised Jehazi showing the large amount of sail which can be set using the lateen rig

INITIAL PERFORMANCE ANALYSIS OF THE SAIL-ASSISTED TUG/FISHING VESSEL NORFOLK REBEL - FUEL SAVINGS AND ECONOMIC RETURN

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Abstract

The design of the sail-assisted tug/fishing vessel Norfolk Rebel is described. The monitoring of her performance in sea trials, on fishing trips and during routine operating conditions yielded over 1,500 observations under varying conditions of wind, sea and sail configurations. Results of analysis of sea trial data and summations of observations taken during fishing operations indicated a representative overall fuel savings of six percent with certain periods of operation showing savings of 20 to 45 percent. The fairly low payback rate by the sail rig as seen in this study may be enhanced by more experience in the offshore fishery and by greater attention to wind patterns in selecting the fishing grounds for each trip. Since the overall savings is heavily dependent on the proportion of transit time in a fishing trip, this multi-purpose vessel would be more competitive in a region requiring longer travel to the fishing grounds.

I. INTRODUCTION

Since the early 1970's, the rising cost of fuel for fishing vessels has taken a growing toll on commercial fishing operations throughout the world. In the United States during the late 1960's and up until 1972, ex-vessel fish prices continued increasing at a faster rate than fuel costs. However, the oil embargo of 1973 caused a dramatic change in this relationship with wholesale prices for #2 diesel fuel increasing almost 900% and gasoline retail prices almost 480% by 1981 (1).

VIMS Contribution No. 1125

Although fuel prices have leveled off somewhat since 1981, they continue to fluctuate and their future remains unpredictable.

An individual fisherman can have no effect on fuel prices, interest rates or fish abundance, but control of fuel consumption is within his power. One of many potential ways to reduce fuel consumption is by the use of sails on fishing vessels. The vessel operator can increase his profit margin by decreasing his fuel consumption if the means used have a reasonable payback.

In 1980, a vessel designed, built and equipped for sail-assisted operations was launched by Rebel Marine Service, Inc. (RMS) of Norfolk, Virginia. The vessel's capabilities included towing, salvage, cargo hauling and fishing. This vessel, the Norfolk Rebel, provided an opportunity for determining how sail-assist affects fuel consumption in certain types of fishing operations. Attention was also paid to vessel safety, crew efficiency and "come-home" capabilities as they were affected by the use of sails.

With support from a grant from the National Marine Fisheries Service, performance data were collected during sea trials, test runs and actual fishing operations. Through the grant, analysis of the vessel's fuel consumption was performed with assistance from the Computer Center and the Virginia Sea Grant Program's Marine Advisory Service at the Virginia Institute of Marine Science, College of William and Mary.

II. APPROACH

A. Vessel Design and Construction

Rebel Marine Service, Inc. commissioned the design of the Norfolk Rebel by Naval Architect Merritt Walter of Rover Marine, Inc. Both firms are located in Norfolk, Virginia. The design parameters established by Rebel Marine included:

- Vessel to be used for fishing, towing and cargo.
- Vessel to have good performance under sail and power.
- Vessel to have short mast height and large sail area.
- Accommodations to be adequate for up to six crew members.

The resultant "TUGANTINE^{R}" specifications (see Appendix A) are as follows:

Length on Deck . .	51.5 feet (15.7 meters)
Beam (maximum) . .	15.2 feet (4.6 meters)
Draft (light) . . .	5.5 feet (1.7 meters)
Nominal Sail Area .	1400 sq. feet (130 sq. meters)

The lines for the vessel were computer-processed by Rover Marine to determine righting angle and tons-per-inch immersion, and were computer-lofted for ease of construction. She was designed to meet or exceed the American Bureau of Shipping scantlings.

Arrangement of the vessel includes an insulated fish hold amidships with a volume of 800 cubic feet (23 cubic meters), capable of holding about eight tons (seven metric tons) of ice and fish. The area forward of the hold is given to the crew's quarters which are sufficient to accommodate four or more crew members. Aft of the hold, amidships and in the area of greatest beam, is the galley, main salon, captain's cabin, and head with shower. Farther aft is the engine room, and in the stern a large lazarette for equipment storage. Fuel and water tanks are built into the box keel. There are five watertight compartments. The Norfolk Rebel has a capacity of 900 gallons (3400 liters) of diesel fuel and 350 gallons (1325 liters) of water.

The Norfolk Rebel is rigged as a gaff schooner for several reasons. It offers a large sail area for the shortest possible masts. The mast height must be less than 65 feet (19.8 meters) from the waterline because the vessel often works in the Intercoastal Waterway under bridges. A gaff rig is less efficient than marconi upwind, but more efficient off the wind. Though the Norfolk Rebel can work its way to windward under sail if need be, normal procedure is to drop the sails and motor upwind. Although a gaff rig is more labor-intensive, the initial cost is lower than for roller-furling marconi rigs. (The "extra" labor needed for the gaff rig has no effect on the Norfolk Rebel's complement because four or five people are carried for fishing trips and only two are required to raise, lower or reef the sails.) The masts are raked aft so that no backstays are necessary; a backstay would hamper fishing operations and prevent the vessel from performing tows.

Construction of the vessel was conducted under the direction of Howdy Bailey, Master Builder, of Customs Unlimited (Norfolk, Va.). All welds in the steel plate hull were ground and checked for pin holes. The completed hull was then sandblasted and painted with Devoe's inorganic zinc system to prevent rusting. The vessel was launched on May 22, 1980. Subsequently the wiring, interior, and engine were installed, followed by the masts and rigging. Outfitting the vessel and equipping it for fishing took a total of one and a half years. The difficult economic times and subsequent reduction in available towing and salvage work resulted in cash flow problems which delayed the final fitting out for fishing operations.

The vessel is equipped to undertake two major types of fishing: longlining for swordfish and bottom-fishing for snapper, grouper or sea bass. Longlining equipment includes a hydraulic reel with level winder, holding ten to twelve miles of mainline. Three to four hundred hooks are spaced evenly along the mainline, with a ball every three hooks and a high flyer every mile. The bottom-fishing equipment consists of four electric and two hand reels, each equipped with a heavy sinker and from two to six hooks.

In addition, the test vessel carries an extensive array of electronics to aid her in navigation, fish-finding, and performance monitoring. For navigation, the Norfolk Rebel is equipped with an Epsco C-Nav XL Loran coupled to a C-Plot II plotter. There are an Epsco FO-2 radar with 32-mile range, two Epsco RT-78 synthesized multichannel VHF/FM radiotelephones, and a Ritchie 6-inch steering compass.

Fish-finding equipment consists of a Epsco CVS-888 color video depth sounder and a Wesmar 165 color scanning sonar. There is also a Dytek sea water temperature gauge.

Primary to the performance monitoring are a Datamarine apparent wind speed and direction indicator and a Datamarine knotmeter/log unit. A Fleet Facts fuel flow monitor shows the fuel consumption rate and the total fuel used. The Loran C gives vessel speed over the bottom.

B. Performance Monitoring Methods

The performance of the Norfolk Rebel was monitored for the assessment of the use of sails as an auxiliary power source for vessels engaged in coastal fishing operations. Observations were made of crew performance and vessel performance during sea trials and during normal fishing operations. Descriptions of the data collection methods follow.

1. CREW ACCEPTANCE AND VESSEL HANDLING, SAFETY AND SEAWORTHINESS

Observations were made during sea trials, fishing trips and during routine free-running transits to assess the crew's acceptance of sail-assist, the vessel's ease of handling and the effect of sails on safety and seaworthiness. Interpretation of these observations was done with explicit reliance on the captain's judgement and experience in the handling of vessels of this type.

2. ESTIMATION OF REPRESENTATIVE FUEL CONSUMPTION

Four tasks made up this portion of the project: (a) data collection, (b) data editing, (c) error assessment and (d) data correlation.

a. Data Collection.

Data logging sheets were set up to record the date and time of observation, apparent wind speed and direction, vessel speed through the water, vessel speed over the bottom, engine speed, fuel consumption rate, sail configuration, sea conditions, and "remarks". The "remarks" column was used for noting the amount of ice and fish in the hold, plus other factors likely to influence the vessel's performance.

Vessel speed, engine speed, wind speed, wind direction and fuel consumption were measured electronically, displayed by instruments and logged by the pilothouse watch. All other parameters were estimated by the pilothouse watch.

Controlled sea trials were conducted jointly by RMS and VIMS personnel in Willoughby Bay (Norfolk, Virginia) at various times between December 1981 and August 1982. This body of water was chosen for its minimal tidal currents and good protection from wind-generated wave action. Trials were conducted under various conditions of wind speed, sail configuration, and engine speed. During these "controlled" sea trials, the observations were logged at frequent intervals (thirty to ninety seconds) while the vessel was running prescribed courses. Since the sea trials were dedicated completely to the testing of the vessel, as opposed to operations during which data logging was auxiliary, the sea trial data provide the most consistent and precise data in the set. Three hundred twenty four data points were collected during these "controlled" sea trials.

Data acquisition on fishing trips was done at regular intervals as demands on the pilothouse watch would allow. Observations were also collected under free-running conditions whenever possible. This set of observations provides information on a much broader range of operating conditions, but has less precision because of the involvement of the watch in other activities, because of the varying individual interpretations of the readouts of the instrumentation and because of the variability of the conditions under which the observations were made. During routine vessel operations, 1209 observations were logged.

The observations were keyed into the VIMS Prime 750 computer from the data logging sheets and reformatted for access by a standard statistics and graphics package.

b. Data Editing.

Correct transcription of the data was checked by visual comparison of each entry against the original logs. Typographical errors were thus reduced.

Extreme data points were located by graphical presentation and by statistical summary of each of the parameters. Some data points were thus recognized as outliers and were referred back to the data logs. If the data transcription was correct, the conditions under which the observation was made were inspected. If the conditions were appropriate for the data group being examined, the observation was left in the data set as a normal deviation. In some cases, observations were found which were not representative of normal vessel operations, e.g., instances of towing a sea anchor or another vessel. These data points were removed from the data set.

c. Error Assessment.

With specific quantitative knowledge of the errors associated with a series of observations, an analytical derivation of the precision of the observations can be made. Without such knowledge, the estimation of precision and, conversely, the estimation of uncertainty must be done statistically.

Analytical quantification of the errors in the observed data was not attempted for two reasons:

There was no capability for precise calibration of the sensors and readouts of the instruments used in determining vessel speed, wind speed and direction, fuel use and engine speed. The assessment of the stability of the instrumentation had to depend on the crew's experience with the vessel and her performance.

The observations depended a great deal on the individual who was logging the information. The high rate of variability in several of the parameters required an "optical averaging" of the instruments' readings. In the cases of fuel use and vessel speed, digital readouts with half-second updates left much to the interpretation of the observer. Additional interpretation was involved in the assessment of the amount of ice and cargo in the hold, as well as the type (chop or swell) and height of the seas in which the Norfolk Rebel was working.

Statistical quantification of data precision was used for this study. Difficulties arose here also because of the many variables inherent in the wind-sea-vessel interaction and the relative sparseness of the data set.

In addition to sail configuration and engine speed, motor sailing performance depends heavily on three environmental parameters: wind speed, wind direction and sea state. The collected data were not continuous across the whole range of values for any of the recorded parameters. If a comparison was to be made by selecting one value of wind speed, one value of wind direction and one value of sea state, there were not necessarily any corresponding values for vessel speed and fuel consumption.

Instead of specific values for these environmental parameters, ranges of wind speed, wind direction and sea state were established to provide larger sets of data for each desired comparison of sail configurations. Although this method did provide more data points, it also introduced additional uncertainty in the results because the slightly different conditions over the sample contributed to variations in the observed performance. An attempt was made to select regimes or ranges of wind and sea conditions within which the vessel performance would vary as little as possible. The groupings of wind and sea conditions are shown in Table 1.

Table 1.
Grouping of Wind and Sea Conditions
For Sea Trial Analysis

Apparent Wind Speed (knots)	5-9	10-16	17-21	22-26
Apparent Wind Direction (degrees)	0-49	50-150	151-180	
Wave Height (feet)	0-3	3-6	6-9	9-12

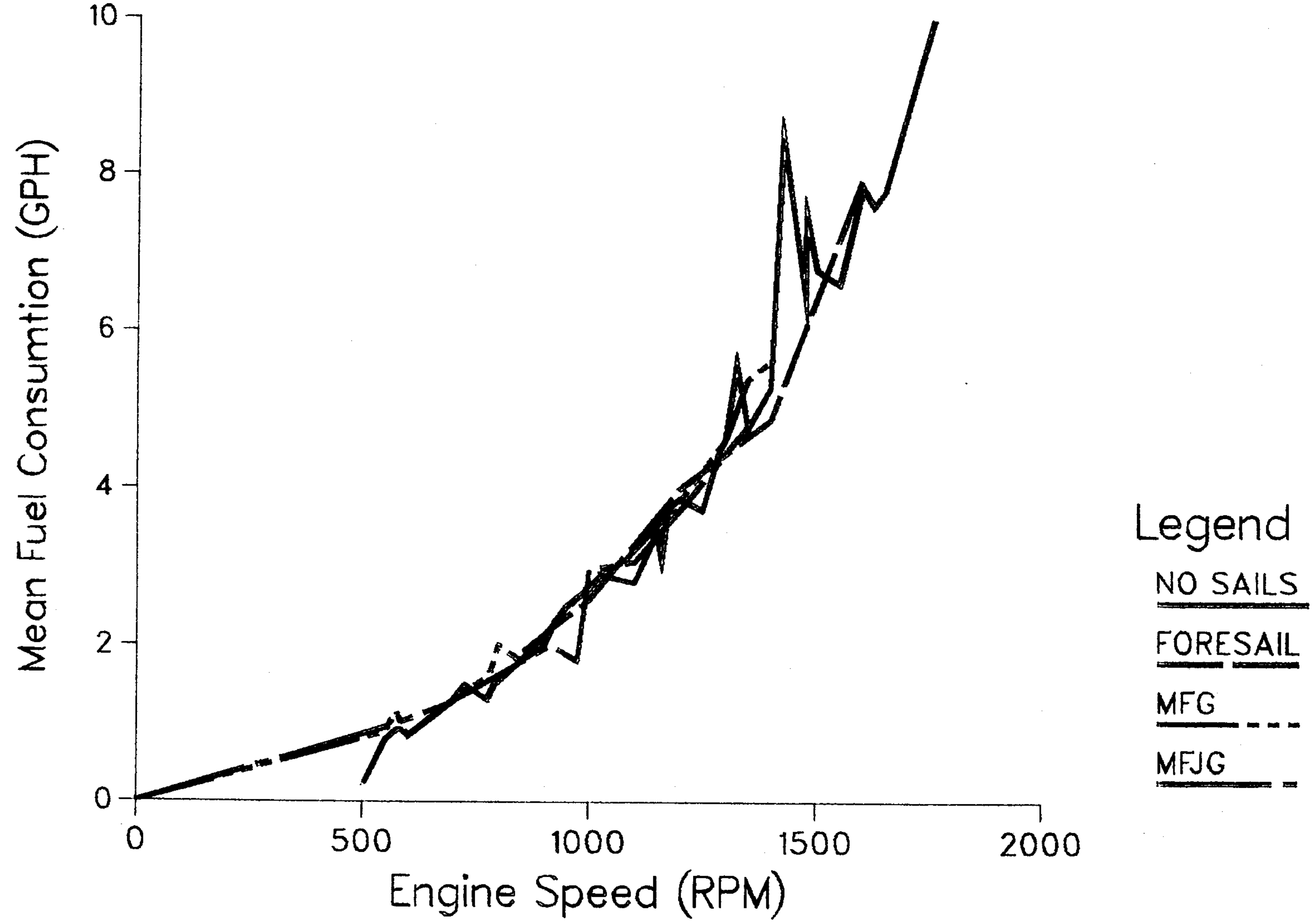
Observations were logged for all the conditions encountered. Winds speeds encountered during fishing trips were predominately in the range of 8 to 16 knots. For simplicity, the presentation of the sea trial data will be limited to winds of the 10 to 16 knot range. Winds of less than 10 knots are of lessor importance in fuel savings and winds of greater than 16 knots were not often seen during the sea trials.

d. Data Correlation.

The following parameters were found to be significant to fuel consumption within the resolution of the study: vessel speed through the water, wind speed and direction, engine speed, sail configuration and sea state. The data show a fairly steady relationship between fuel consumption and engine speed regardless of sail configuration or vessel speed. Figure 1 shows this relationship for several sail configurations.* Because of this behavior and because the primary interest is in the amount of fuel needed to get from point A to point B regardless of engine speed, the comparisons of different sail and motor configurations are presented directly in terms of vessel speed versus the rate of fuel consumption, independent of engine speed.

*The following abbreviations are used in the figures and tables: M - Main, F - Foresail, J - Jib and G - Genoa.

Figure 1. Engine Speed vs Fuel Use For 4 Sail Configurations



For all wind and sea conditions

Figures 2 through 5 show scatter plots of the relationship between the vessel speed and fuel consumption rate for engine with foresail; for engine with main, fore, and genoa; for engine with main, fore, jib and genoa; and for engine-only operation. The second plot in each figure shows the mean of the consumption rate at each discrete value of vessel speed. The scatter and lack of smoothness of this data do not allow simple comparisons of fuel consumption at arbitrary vessel speeds.

To smooth the data and to provide a consistent means for comparison at any specific vessel speed, curves were fitted to the observed data. The foresail sea-trial data were not analyzed further because there were not enough observations. Third order polynomial equations were initially fitted to observed data for each of the remaining sail/engine configurations. For the motor-sailing observations, the fitted curves were not well behaved in the regions of interest, so the speed/fuel relationship for each of the motor-sailing configurations was modeled by a cubic equation of the type

$$\text{FUEL} = \text{K} \times \text{SPEED}^3 + \text{C}$$

where K and C are constants determined by the fit. The curve fitting was done by a linear regression of the fuel consumption values against the cube of the speed values. A standard error of estimate (the standard deviation of the residuals) was then calculated for each set of data, providing an estimate of the predictive capability of each curve.

There were enough observations made during sea trials of engine-only operation to give a smooth third-order polynomial fit to these data. Figures 6 through 8 show the sea trial data with the fitted curves.

The curve in Figure 9 represents the fuel consumption relationship under power alone for all conditions. Approximately 780 readings of fuel consumption under engine alone were logged over the course of the project under various wind and sea conditions. Sufficient data were available here to generate a well-behaved monotonic polynomial. This curve was generated by a least-squares fit of a third-order polynomial to all the logged data that were representative of routine vessel operations. An additional constraint to the fit was the inclusion of dummy readings indicating zero fuel consumption at zero vessel speed to force a realistic behavior on the polynomial as it approached zero.

It can be seen in several instances that the fitted curves are reasonable only for certain regions of vessel speed. Extrapolation beyond the regions containing observed data should be viewed with caution. The use of these curves was restricted to the well-behaved regions.

3. USE OF SAILS IN FISHING OPERATIONS

Sixteen fishing trips were made between November 1981 and November 1982. Nine trips provided insufficient data for numerical analysis due to rough conditions, seasickness or monitoring equipment malfunction.

The seven remaining trips provided 333 observations of the vessel's performance in three different types of fishing (bottom fishing, longlining and trolling).

In order to determine the savings (if any) under sail during the fishing operations, it is necessary to compare the observed consumption under sail with an estimate of engine-only fuel consumption for the same conditions.

The base-line curve developed from the entire sample of engine-only observations (Figure 9) was calibrated for the fishing trips by using it to predict fuel consumption for the engine-only observations taken during fishing trips. It was found that the base-line curve was seven and one-half percent low in predicting the average consumption rate for these observations. Detailed investigation of this behavior was not undertaken at this time, but instead an "open-water" correction factor of 1.075 was applied. This re-calibrated base-line yielded a mean residual error of 0.0 gallons per hour with a standard error of estimate of ±0.66 gallons per hour for the 192 engine-only observations in the sample.

A plot of the engine-only performance during fishing trips is shown in Figure 10 with the "open-water" base-line curve.

Figure 2. Fuel Use Rate vs Vessel Speed

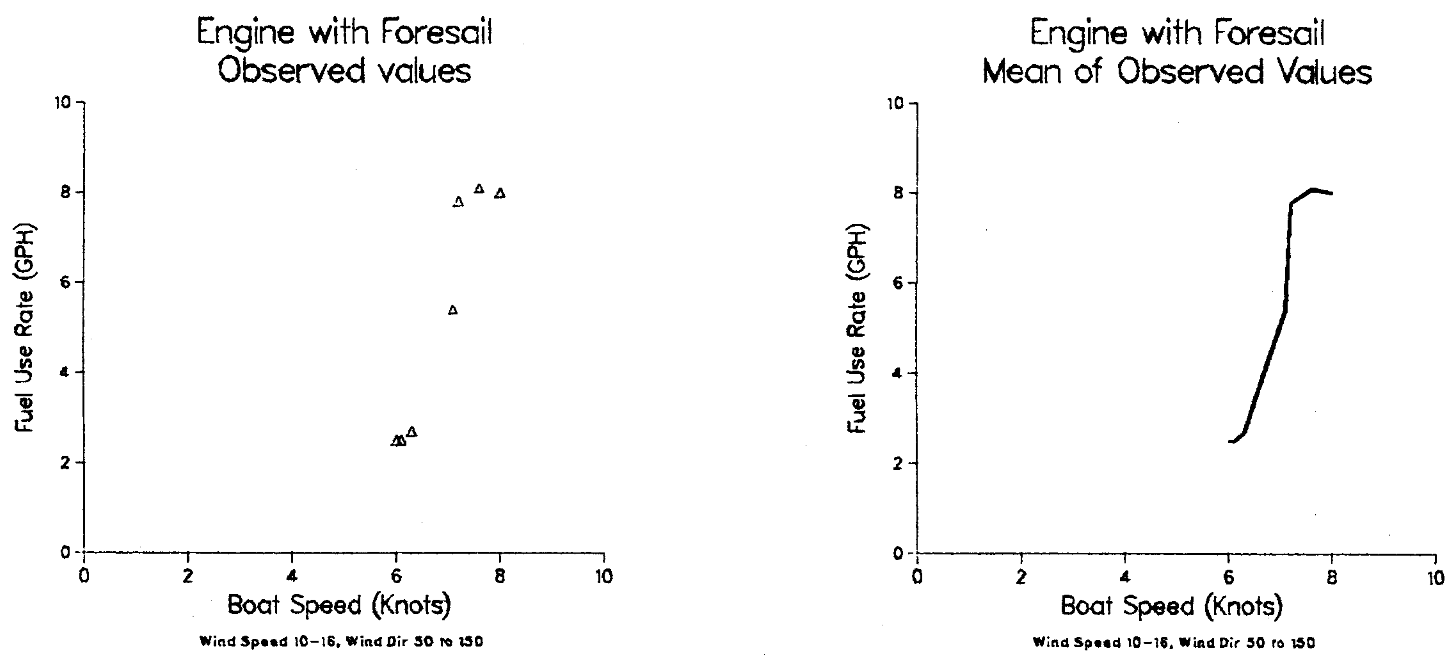


Figure 3. Fuel Use Rate vs Vessel Speed

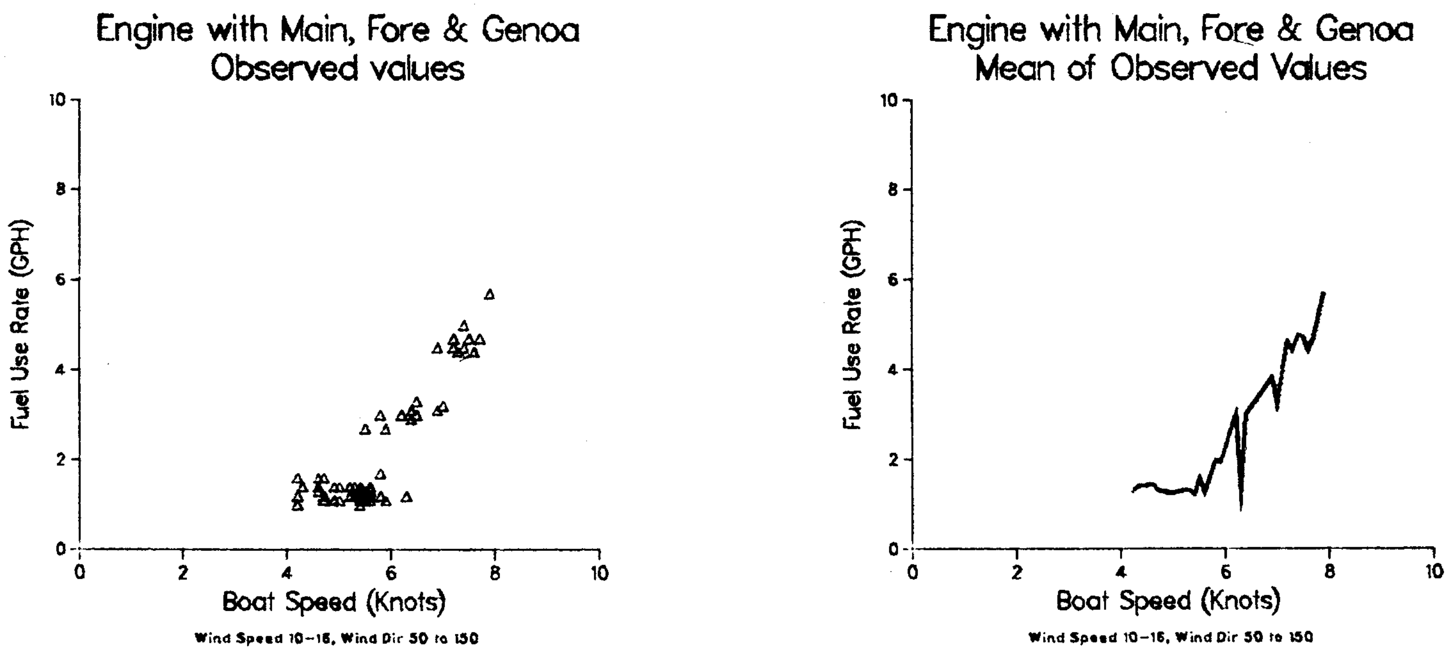


Figure 4. Fuel Use Rate vs Vessel Speed

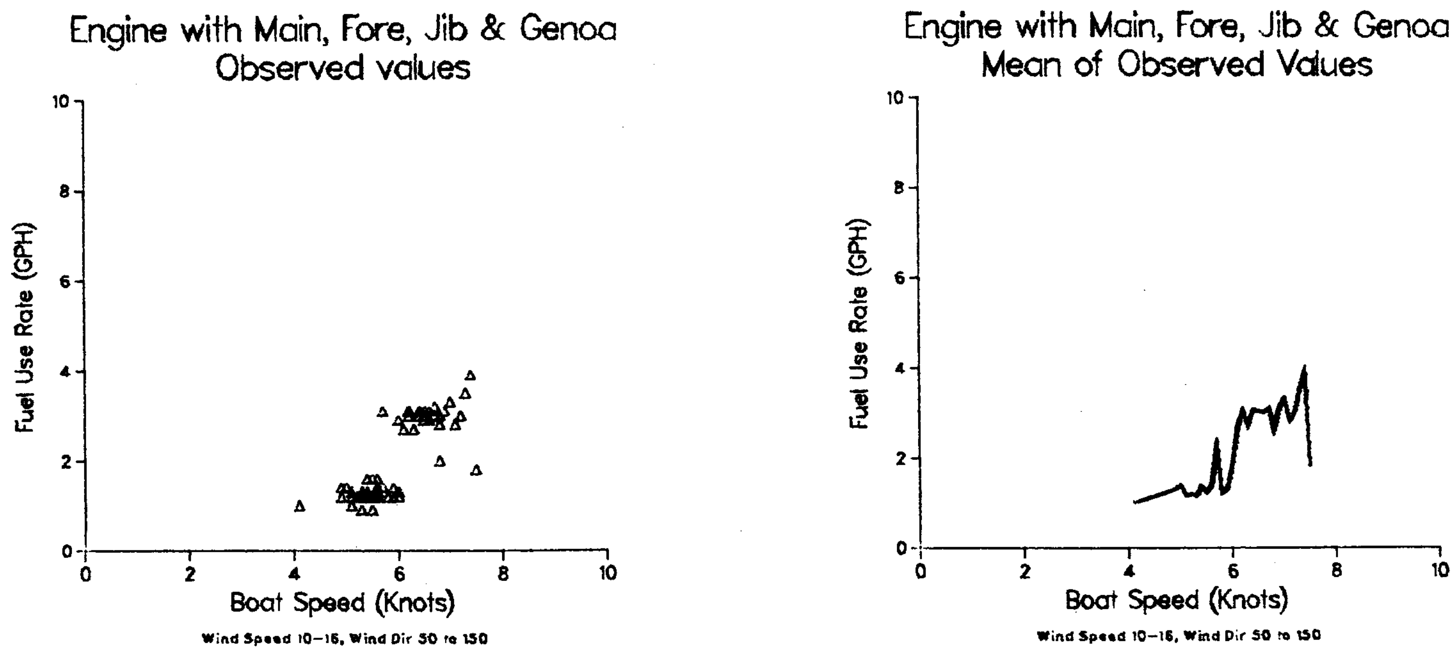


Figure 5. Fuel Use Rate vs Vessel Speed

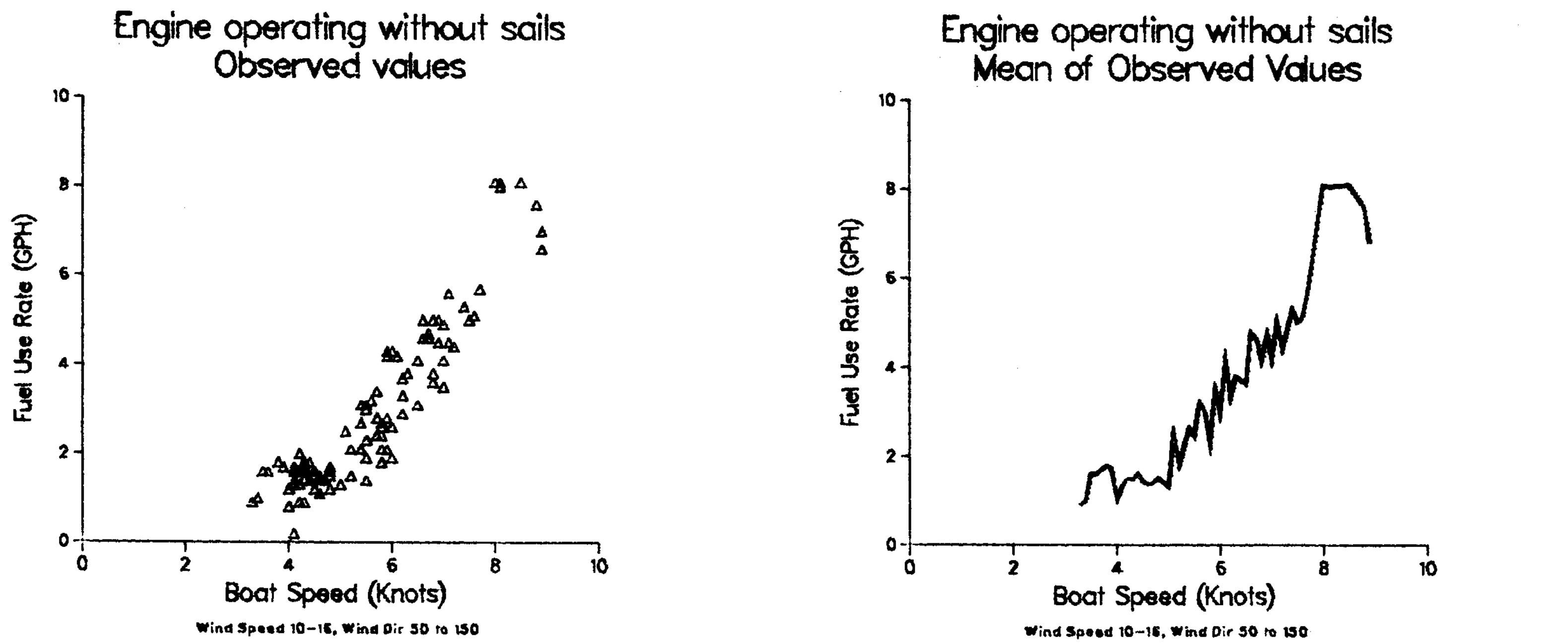


Figure 6. Fitted Curve of Fuel Use vs Boat Speed
Engine with Main, Fore & Genoa

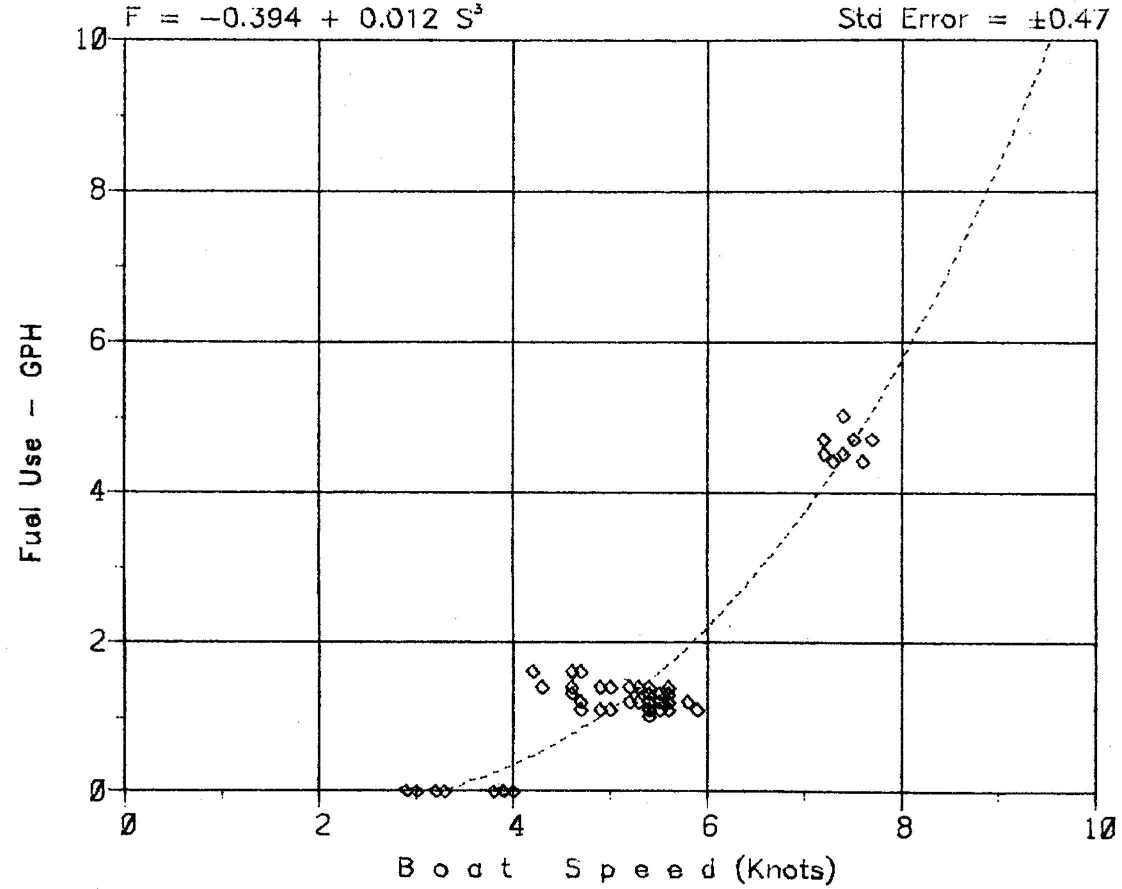


Figure 7. Fitted Curve of Fuel Use vs Boat Speed
Engine with Main, Fore, Jib & Genoa

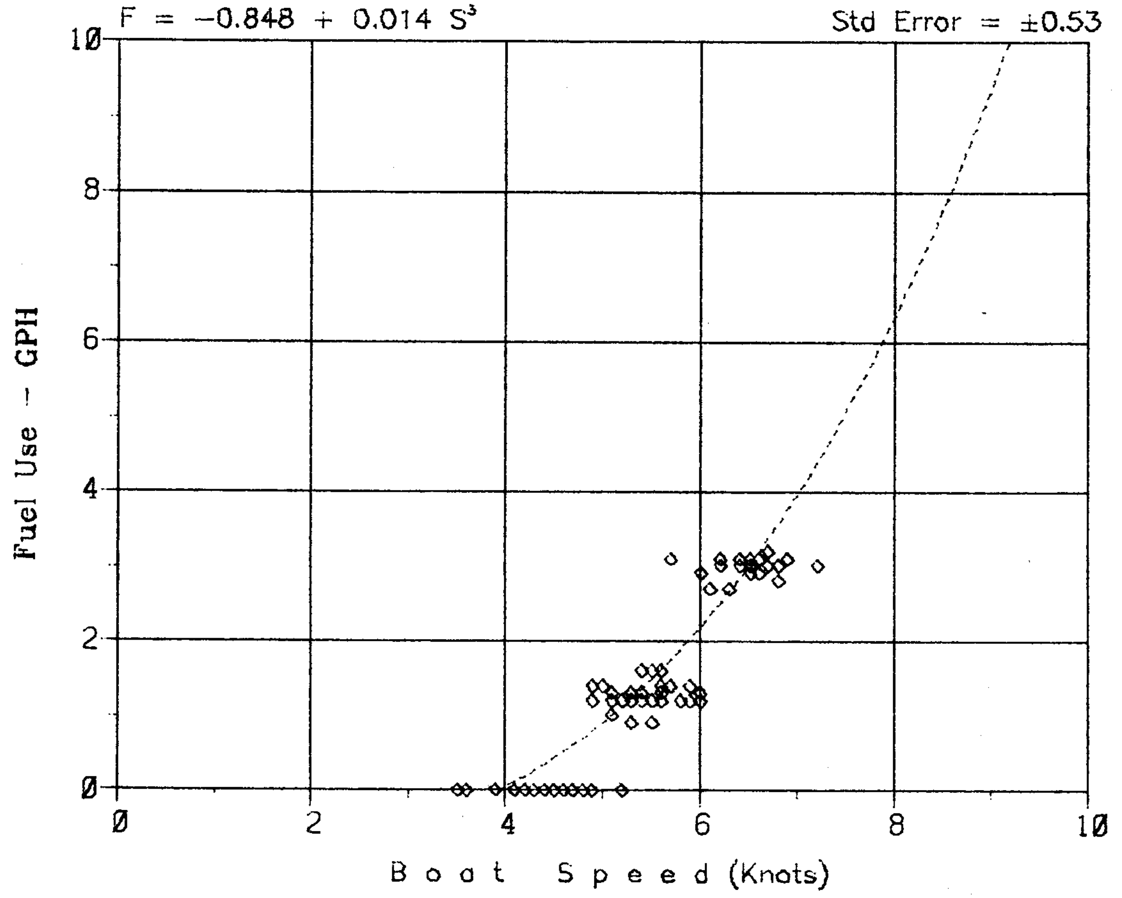


Figure 8. Fitted Curve of Fuel Use vs Boat Speed
Engine Operating Alone - Sea Trials

$F = 0.001 + 0.476\ S - 0.110\ S^2 + 0.021\ S^3$ Std Error = ±0.34

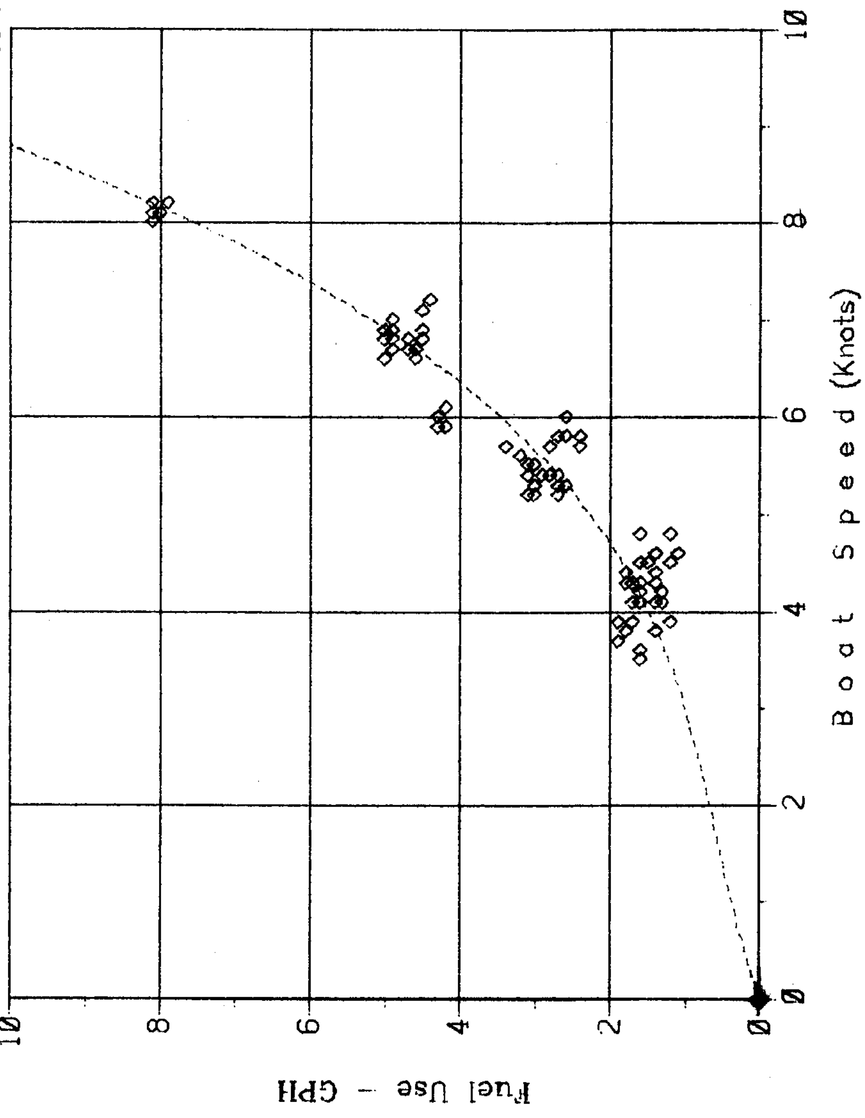


Figure 9. Fitted Curve of Fuel Use vs Boat Speed

Engine Operating Alone — All Observations

$F = 0.010 + 0.011\,S + 0.060\,S^2 + 0.004\,S^3$ Std Error = ±0.75

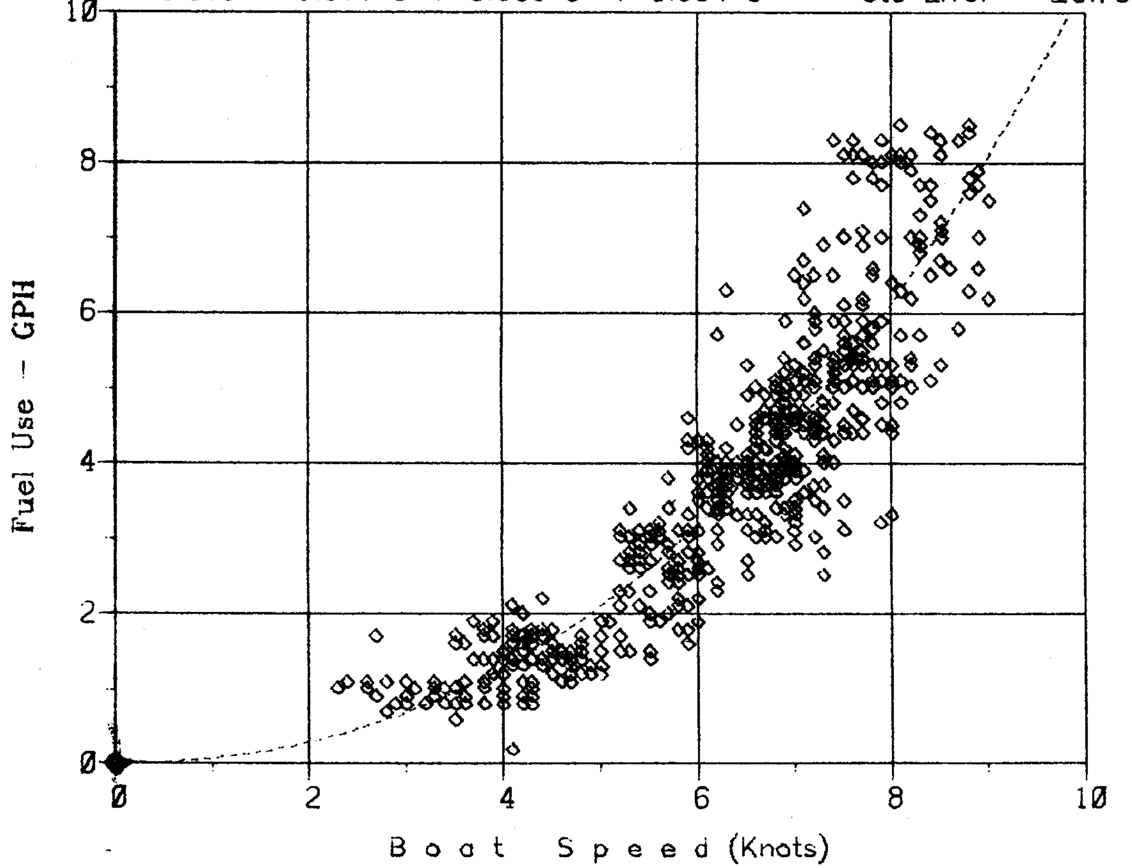
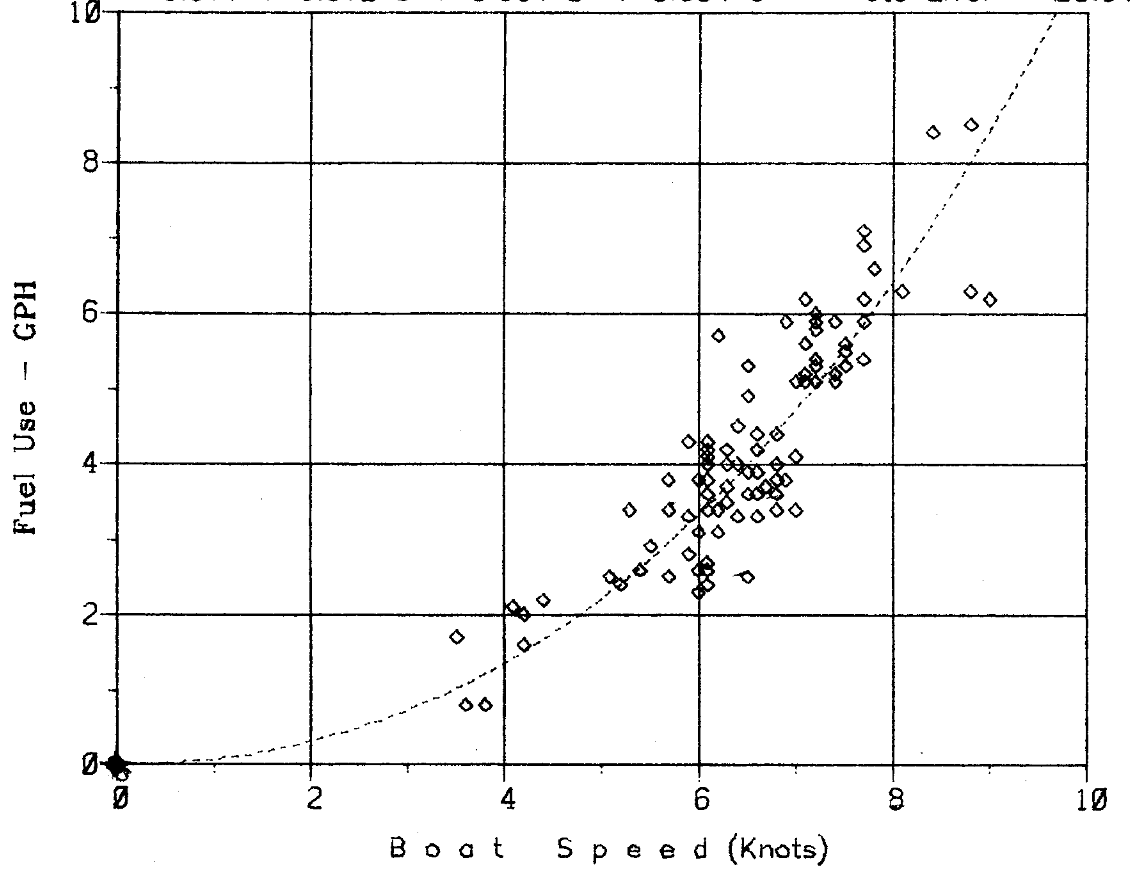


Figure 10. Open Water Curve of Fuel Use vs Speed

Engine Operating Alone – Fishing Trips

$F = 0.011 + 0.012\,S + 0.064\,S^2 + 0.004\,S^3$ Std Error = ±0.64



III. RESULTS

A. Crew Acceptance, Vessel Handling, Safety and Seaworthiness

The fishermen employed on the Norfolk Rebel, both sailors and non-sailors alike, accepted the extra work involved in sail handling because of the reduction in fuel costs and the dampening of the rolling motion of the boat. However, during runs of just a few hours or less, the time needed to raise, trim and lower all the sails was not always worth the effort, especially when there was a lot of gear work to be done on deck.

The use of the gaff rig on the Norfolk Rebel did not require a larger crew nor any change in watch-standing procedures. The sails can be raised or lowered by one person, but it is easier to have two people. Rebel Marine Service's practice is to have two people on watch, so this arrangement is ideal. Novice sailors were teamed with "old salts" and normally could pick up the rudiments of sail handling in just a few trips.

The mainsail and foresail are hoisted with four-part tackles, making this operation fairly easy. In addition, they are equipped with lazyjacks so that the sails stay on top of the booms when lowered. The combination gives a simple and time-tested system for making or reducing sail.

The sheets for the main, fore and staysails are also of four parts. One person can handle sail trimming for these sails in winds under 25 knots. In higher winds, the sheets may be led to winches or another crew member can assist.

When the vessel is working its way to windward, all sails except the genoa are self-tending. The genoa sheets are led to large two-speed self-tailing winches located by the pilothouse doors for easy access by the helmsman. During a tack under main, foresail and genoa, one person lets fly the windward genoa sheet then crosses to the opposite side of the pilothouse to haul in the other sheet on the new tack without going forward.

Electric or hydraulic winches for sail handling, connected to the sheets and controlled from the pilothouse, would reduce the manpower needs under sail; however this equipment is prohibitively costly for this operation. Because there are normally two people on watch at all times, and two can handle almost any situation that may develop, manpower needs under sail were not considered excessive.

The sails on the Norfolk Rebel helped to improve her safety and seaworthiness. The sails acted to steady the rolling motion of the vessel in a seaway providing better footing on deck. This action is similar in effect to the use of paravanes on trawlers but without the underwater drag and corresponding increase in fuel consumption. If the sail-induced heel increased too much for the crew's comfort, it was easy to reef down or lower one or two sails. The vessel was very well balanced and could sail under foresail or genoa alone at a 60-degree apparent wind angle.

During rough weather the Norfolk Rebel would lay to quartering seas under foresail alone. The foresail would be sheeted in tight and the wheel put hard over to the windward side. The vessel would ride comfortably like this for hours without any need for touching the helm or running the engine.

In the event of an engine breakdown, the sails are capable of bringing the vessel safely back to port. If the Coast Guard transfers most of their routine towing duties to commercial firms, as is now under discussion, this "come home" capability may well save a sizeable sum of money for the owner of a sail-assisted commercial fishing vessel.

B. Sea Trials

Given the curves shown in Figures 6 through 8, it is possible to develop a theoretical average fuel savings for each of the wind and sea conditions listed. Table 3 lists several examples of the Norfolk Rebel's average sea-trial performance taken from these curves. Figures 11 and 12 show the algebraic difference between the least-squares fit of each of the 2 motor-sailing curves and the engine-only base-line curve derived from sea trial observations. These plots are restricted to the well-behaved regions of the fitted curves.

The standard error of estimate for each result is the square root of the sum of the squares of the individual standard errors of the appropriate motor-sailing curve and the engine-only curve. The standard error of estimate used here is the standard deviation of the residuals developed when each curve is used as a predictor for the set of data points from which it was derived.

Table 3.
Average Observed Fuel Use Rate (gph) During Sea Trials
In Winds of 10 to 16 Knots, Reaching

Sails In Use	Speed (knots)				
	3	4	5	6	7
Engine only	1.0	1.5	2.3	3.4	5.1
Engine with Main, Fore and Genoa	0.0*	0.4	1.1	2.2	3.7
Engine with Main Fore, Jib & Genoa	0.0*	0.0*	0.9	2.2	4.0

*Zero fuel consumption implies a sail-only configuration.

A comparison of engine-only performance curves derived from the sea-trial data with that derived from the entire set of observations indicates that the power required during the sea trials was about seven percent higher than the average for all observations. This difference may be explained in part by the additional wave induced drag exhibited by a vessel moving close to hull speed in water depths less that her waterline length.

Figure 12. Fuel Savings – Sea Trials

Engine with Main, Fore, Jib & Genoa

$F = 0.859 + 0.476\,S - 0.110\,S^2 + 0.007\,S^3$ Std Error = ±0.67

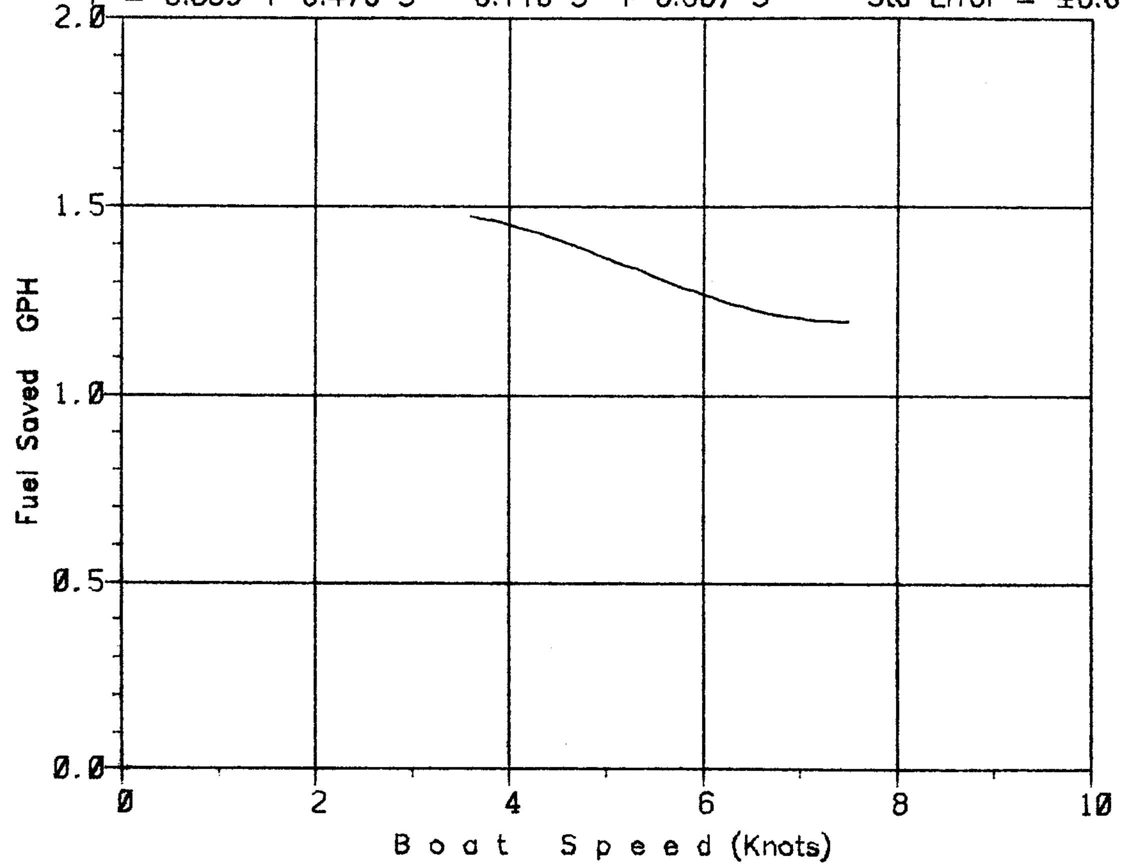
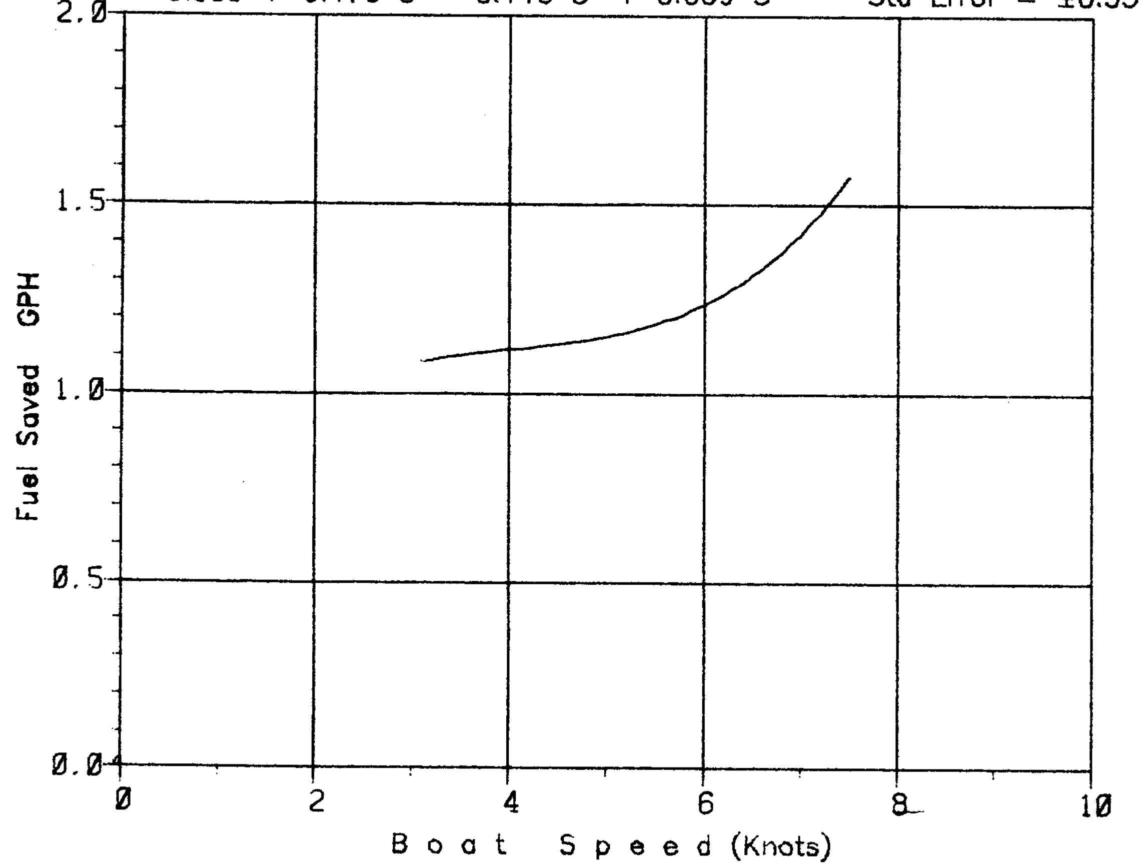


Figure 11. Fuel Savings – Sea Trials

Engine with Main, Fore & Genoa

$F = 0.395 + 0.476\ S - 0.110\ S^2 + 0.009\ S^3$ Std Error = ±0.53



C. Fishing and Sail Use

The fuel consumption for each observation under sail was compared with the fuel consumption predicted by the open-water base-line curve. Table 4 shows a breakdown of the results for each fishing trip having sufficient data.

Table 4.
Trip Summary of Observed and Predicted Performance

Bottom Fishing

Trip	Sail	No. of Observ	Total Time (hrs)	Avg Winds Spd (kts	Dir deg)	Actual Fuel Use (gals)	Predicted Fuel Use (gals)	Fuel Saved** (gals	%)
5									
	F	8	4.1	6.0	90	18.0	24.2	6.1	25
	Head*	7	3.5	13.0	38	15.9	16.2	0.3	1
	Eng	53	25.5	10.6	26	102.7	102.6	-0.1	0
6									
	MF	5	2.5	2.6	58	13.3	15.5	2.2	14
	MFG	18	8.5	4.6	71	23.8	29.8	6.0	20
	Head*	5	2.0	2.2	16	12.9	13.0	0.1	0
	Eng	15	6.6	8.8	24	24.7	29.7	5.0	16
13									
	F	1	0.4	5.0	80	0.4	0.6	0.1	23
	MF	3	2.2	9.9	63	7.0	7.7	0.7	9
	MFG	28	15.7	8.9	67	17.5	35.2	17.8	50
	Head*	9	4.5	9.9	40	15.0	17.5	2.5	14
	Eng	1	0.5	0.0	90	0.6	0.5	-0.1	-15

(Table 4 is continued on the next page)

*Head - Carrying sails, but motoring upwind
**This column gives the savings for the period that the given sails are actually in use.

Table 4 (continued).

Longlining

Trip	Sail	No. of Observ	Total Time (hrs)	Avg Winds Spd (kts	Dir deg)	Actual Fuel Use (gals)	Predicted Fuel Use (gals)	Fuel Saved** (gals	%)
12									
	F	4	2.0	7.2	90	3.8	4.3	0.5	11
	MF	1	0.5	7.0	60	1.4	1.3	-0.1	-4
	FG	19	9.5	7.7	84	5.4	9.6	4.1	43
	MFG	4	1.8	8.8	66	5.1	5.4	0.3	5
	Head*	38	22.7	9.5	24	57.3	50.6	-6.7	-13
	Eng	28	18.7	1.2	11	70.5	64.5	-6.0	-9
16									
	F	4	2.1	16.2	50	9.4	8.8	-0.6	-6
	MFJ	15	7.7	13.6	86	17.5	32.6	15.1	46
	Head*	19	9.5	11.4	31	42.6	43.7	1.1	2

Trolling

Trip	Sail	No. of Observ	Total Time (hrs)	Avg Winds Spd (kts	Dir deg)	Actual Fuel Use (gals)	Predicted Fuel Use (gals)	Fuel Saved** (gals	%)
9									
	MFG	6	0.5	9.3	76	0.1	0.6	0.5	85
	MFJG	8	3.1	8.9	77	0.1	2.8	2.7	97
	Head*	16	2.8	7.6	20	6.2	6.5	0.3	4
10									
	MFG	12	7.5	6.7	90	4.5	8.3	3.8	45
	Head*	1	0.5	7.0	10	0.9	0.9	-0.0	-5

*Head - Carrying sails, but motoring upwind
**This column gives the savings for the period that the given sails are actually in use.

The average fuel savings was determined for each sail configuration used during the fishing trips. Table 5 shows the results along with the number of observations used to determine each average.

Table 5.
Average Rate of Fuel Savings During Fishing Operations
By Sail Configuration

Sails	Rate of Fuel Saving (gph)	No. of Observations
Foresail	0.7	17
Main & Fore	0.5	9
Main, Fore & Genoa	0.8	50
Fore & Genoa	0.4	19
Main, Fore & Jib	2.0*	15
Main, Fore, Jib & Genoa	0.9	8

*This figure represents 7.7 hours on a beam reach with average winds of 13.6 knots (see Table 4, Trip no. 16).

Table 6 shows the percentage of time that the various sail configurations were in use during the fishing trips from casting off to tying up, including time spent laying to and handling gear. Also shown are the accumulated fuel savings for each trip and the percent of fuel saved. Total fuel use as determined by topping off the tanks is given where available.

Table 6.
Sail Use / Fuel Savings Profile

Bottom Fishing

Trip No.	Duration (hrs)	Sail Use* (type	hrs)	Overall % Sail Use	Total Fuel Used	Fuel Saved (gals)	Overall Percent Saved
5	117	F	4.1	4			
		Total	4.1	4	203	6.1	3
6	64	MF	2.5	4			
		MFG	8.5	13			
		Total	11.0	17	96	8.2	8
13	55	F	0.4	1			
		MF	2.2	4			
		MFG	15.7	28			
		Total	18.3	33	80	18.6	18

Longlining

Trip No.	Duration (hrs)	Sail Use* (type	hrs)	Overall % Sail Use	Total Fuel Used	Fuel Saved (gals)	Overall Percent Saved
12	129	F	2.0	2			
		MF	0.5	<1			
		FG	9.5	7			
		MFG	1.8	1			
		Total	13.8	10	206	4.8	2
16	102	F	2.1	2			
		MFJ	7.7	8			
		Total	9.8	10	212	14.5	6

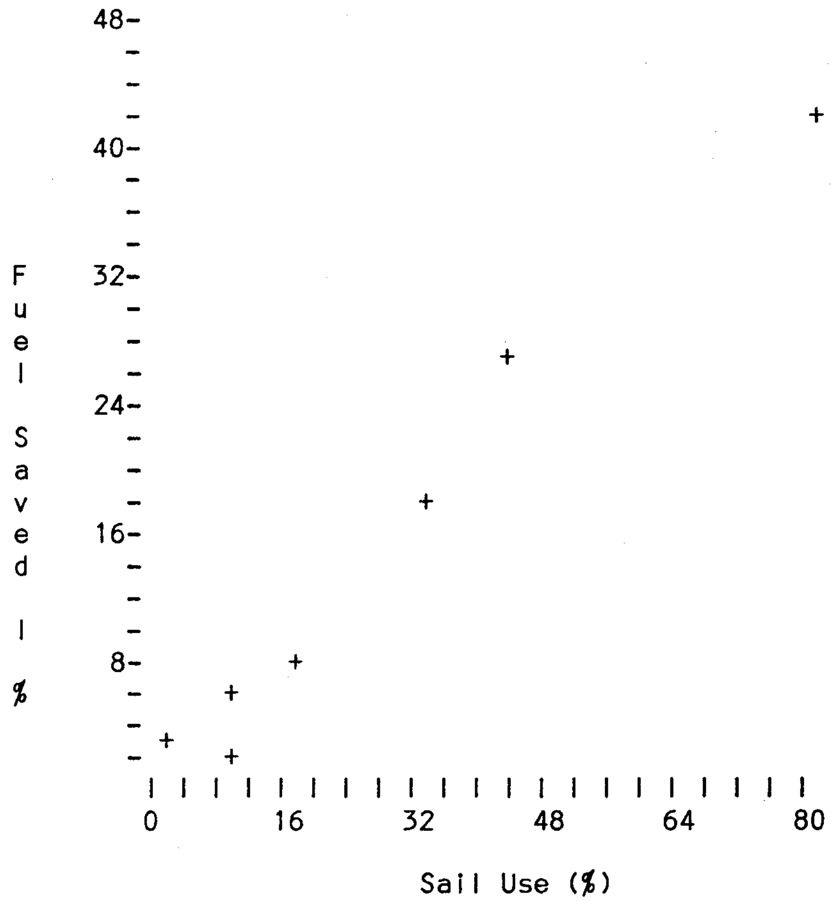
Trolling

Trip No.	Duration (hrs)	Sail Use* (type	hrs)	Overall % Sail Use	Total Fuel Used	Fuel Saved (gals)	Overall Percent Saved
9	8	MFG	0.5	6			
		MFJG	3.1	39			
		Total	3.6	45	11**	3.2	29
10	9	MFG	7.5	83			
		Total	7.5	83	9**	3.8	42

*Sail use figures include motor-sailing and sail-only operation.
**Estimation based on vessel operation.

Figure 13 makes evident the relationship between the percentage of time that the sails are in use and the percentage of fuel saved on a trip by trip basis.

Figure 13.
Percent of Fuel Saved vs Percent of Time That Sails are in use



IV. DISCUSSION AND CONCLUSIONS

Two aspects of the fuel savings analysis on the Norfolk Rebel must be examined to evaluate her performance. Both her overall savings during fishing trips and short term savings during portions of trips should be studied to best analyze the sail rig's contribution to the vessel. First, the overall savings picture will be considered.

The overall fuel savings for three bottom fishing trips range from 3 to 18 percent and for two longlining trips, 2 to 6 percent (Table 6). When one examines the percentage of time sails were used on each of the trips (Table 6), it becomes apparent that this aspect of the vessel's operation is a major limiting factor in its fuel savings record. On the bottom fishing trips sails were used only a maximum of 33 percent on one trip while the other trips exhibited sail use 4 and 17 percent of the time overall. Longlining trips showed a 10 percent use of sails.

Estimated savings for two trolling trips were 29 and 42 percent. The percent of sail use for these trips was 45 and 83, respectively, indicating that sail-assist may be well suited to this type of operation. In the mid-Atlantic region, few commercial fishermen find trolling operations to be economical; however, commercial trolling fisheries play a greater roll in the overall fishing effort of other regions.

A computer analysis of the feasibility of retrofitting sailing rigs on snapper-grouper boats working out of Florida's Gulf coast ports indicates these vessels should be able to use their sails about 60 percent of the time (3). In this same study, even a conservative 30 percent use of sail-assisted power is estimated to provide reasonable fuel savings for the 400-mile round trip to the grounds. Given the obvious relationship between the percentage of time the sails were used and the overall fuel savings observed (Fig 13), an increase in overall sail use would significantly enhance fuel savings.

Scheduling of fishing operations around offshore weather conditions would maximize the percentage of time that sail could be used. During the test period in which fishing trips were made, salvage-towing job demands on the vessel significantly restricted the scheduling of such trips. It is likely that more experience with offshore wind patterns and full-time devotion of vessel use to fishing would result in greater fuel savings rates overall.

Average wind speeds observed during the fishing trips made for this study were 9.2 knots. On the average, 11 to 21 knot winds are observed over the mid-Atlantic continental shelf 42 percent of the time in March and April, 46 percent from May to August and 47 percent from September to November (4). Therefore, sufficient wind magnitudes should be available during the fishing season to permit reasonable rates of sail-assisted power use.

While overall fuel savings were low for the initial fishing experiences of the Norfolk Rebel, the examination of short-period savings during trips better indicates the vessel's potential. During bottom fishing trips, 50 percent fuel savings were achieved by using the sails over a 15.7 hour run (Trip 13, Table 4). On two other trips 20 and 25 percent savings were realized over 8.5-hour and 4.1-hour runs respectively (Trips 6 and 5, Table 4). Similarly on the longline trips, runs of 9.5 hours and 7.7 hours resulted in 43 and 46 percent fuel savings respectively (Trips 12 and 16, Table 4). Even higher fuel savings were achieved on trolling trips, but as mentioned previously, not much trolling is done by commercial fishing boats (except charter boats) in the mid-Atlantic region. Again, as the vessel owners gain more experience with offshore sea conditions and wind patterns, they may realize such higher fuel savings for a greater proportion of their total offshore trips and so approach an overall savings in the range of 20 to 30 percent.

In looking at typical runs made to the offshore fishing grounds out of Chesapeake Bay for longlining and some wreck fishing, such runs are usually in the range of 70 to 75 miles. If the vessel could achieve overall fuel savings of 25 percent on runs to and from these grounds at a cruising speed of seven knots, then a savings of approximately thirty dollars per trip could be realized (at fuel prices of $1.20 per gallon). If 20 such trips per year were made, then an annual savings of about $600.00 would be accrued. This amount of potential savings indicates that unless considerably longer trips were the rule in the mid-Atlantic region, payback on the sail-rig investment would occur at an unacceptable rate. However, if trips of twice the indicated distance were the usual case, an annual savings of about $1,200.00 would be realized and the economics of sail-assist would look considerably better.

In summary, the larger the percentage of time the sails are in use, the more savings achieved over the period of a trip. For best fuel savings, the selection of the grounds should be made with an eye to the winds likely to be encountered on the trip. A beam reach out and back is much more economical than head winds out and tail winds back. If fishing strategy could include longer trips, the economic return attributed to sail-assisted fuel savings would be enhanced. Extending his vessel's operating range without any penalty in fuel consumption provides a fisherman with the advantage of working grounds economically inaccessible to his local competition.

In a sail-assisted vessel designed just for fishing, the use of sails must be relied on for a substantial portion of the motive power. The subsequent effect on the vessel design is that the engine placed in the vessel may be smaller. This means a lower initial cost and a lower operating cost. This was not the situation for the Norfolk Rebel as her capabilities, by design, included towing and salvage work. If this type of trade-off had been possible for the vessel, then a better relative economic return from the use of sails might be realized.

This analysis of the Norfolk Rebel's performance during her first year of fishing operations indicates that even with a vessel designed for as divergent types of activities as towing, salvage and fishing, some economic savings can be realized using sail assist. As more experience is gained in the offshore fisheries by the vessel, it appears likely that greater savings can result. Since the vessel has also demonstrated the ability to work on long runs both north and south of

Virginia, it may prove able to compete in fisheries in these areas, unlike other Virginia boats of similar size, because such long runs maximize her sail-assisted power advantage.

ACKNOWLEDGMENTS

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APPENDIX A

TUGANTINE[R] NORFOLK REBEL

Specifications

Length on Deck	51 feet	Beam	15 feet
Waterline Length	48 feet	Draft	5.5 to 6.5 feet
Overall Length	59 feet	Displacement	33 to 42 tons
Construction	steel	Ballast	8 tons internal
Main Propulsion		**Auxiliary Propulsion**	
Power	320 hp diesel	Sail Area	1123/1707 sq.ft.
Wheel	44x40 4-blade	Rig Type	Gaff Schooner
Reduction	4.5:1	Rig Height	48 ft. above LWL

Electronics

Chromascope
Loran C and Plotter
Sea Water Temperature Gauge
2 VHF/FM Radiotelephones
Radar w/ 32-mile range
Color Sonar

Equipment

Towing and Pushing Gear, Retractable Bowsprit
Generator
Full Diving Equipment
11 gpm Hydraulic Pump
Longlining and Bottom Fishing Gear, Insulated Hold
2" and 3" Salvage Pumps
Wood and Metalworking Tools
Winch

Accommodation

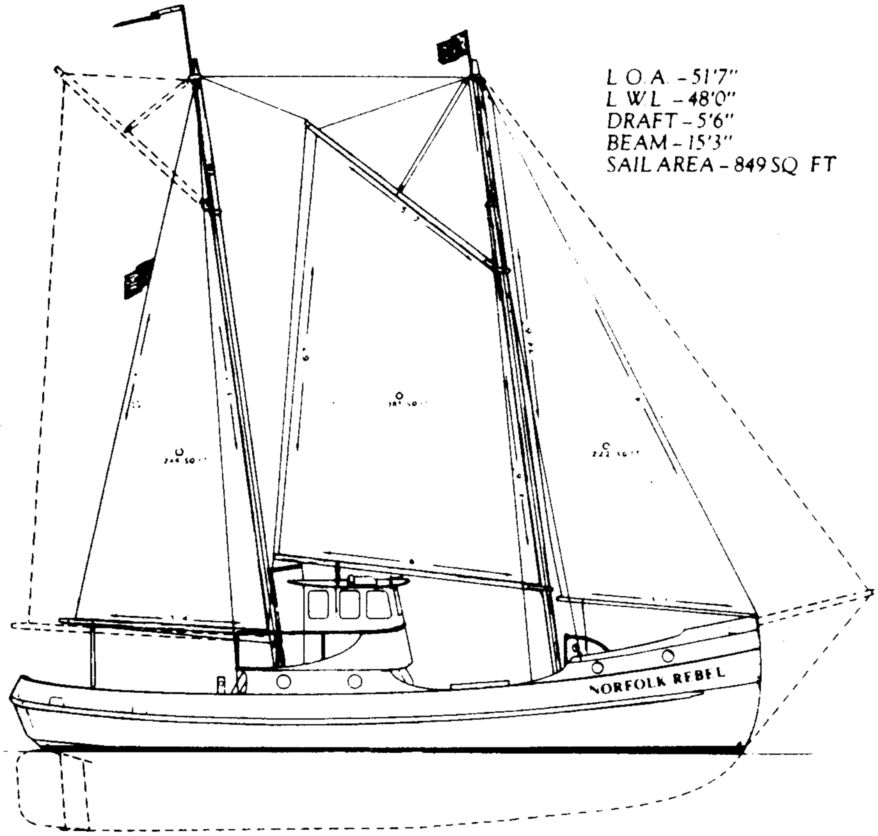
Capt. & Crew quarters for 5/6
Wheelhouse with pilot berth
Full Galley w/ Dining Area
Head with shower

Other

Fuel Monitor
Knotmeter and Log
Apparent Wind Speed/Direction
2-Speed Sheet Winches

Capability

Fishing - Salvage - Towing - Cargo - Research - Search - Support



TUGANTINE®

NORFOLK REBEL

Built for Captain Lane A. Briggs
Rebel Marine Service

Designed by Merritt N. Walter
Rover Marine

Master Builder, Howdy Bailey

BIOGRAPHICAL SKETCHES

Captain Jesse Briggs is a corporate officer of Rebel Marine Service, Inc. in Norfolk, Virginia. He is the captain of the 46-foot tug Steel Rebel as well as captain of the 71-foot sail-training vessel (Skipjack) Norfolk. He has a First Class Uninspected Towing License and commercial diving experience.

Robert Lukens has a B.S. degree in Ocean Engineering from the Massachusetts Institute of Technology with course work in naval architecture. He has worked in instrumentation and computer analysis for the Environmental Devices Corporation in Marion, Massachusetts and as an engineer for Deepsea Ventures, Inc., Gloucester Point, Virginia. He is currently with the Computer Department of the Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, Virginia.

Jon Lucy has an M.A. in Marine Science and is associated with the Sea Grant Marine Advisory Service of the Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, Virginia. He was the principal liaison between Rebel Marine Service, Inc. and VIMS during the course of the work on the Norfolk Rebel and coordinated the National Conference on Applications of Sail-Assisted Power Technology in Nolfolk, Virginia during 1982.

FUEL CONSERVATION IN THE GULF AND SOUTH ATLANTIC FISHING FLEET

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ABSTRACT

The southeastern shrimp industry is the most valuable fishery in the United States. The Gulf of Mexico shrimp fishery in 1979, accounted for 60 percent of the volume and 80 percent of the value of the total U.S. shrimp fishery, valued at $472 million dollars.

For the Gulf fleet, fuel and oil account for 40-54 percent of total operating cost for vessels over 50 ft. The Gulf shrimp fleet consumes 33 percent of the diesel fuel used by the U.S. fishing industry; the shrimp industry is second only to the Maine lobster industry in energy inefficiency per unit of protein produced.

Recent trends have been toward construction of larger, more powerful vessels. Of vessels constructed in the Gulf and South Atlantic since 1970, 62 percent are larger than 55 ft. as opposed to 18 percent prior to 1960. Since 1970, 57 percent have more than 200 horsepower as opposed to only six (6) percent of vessels built prior to 1960.

A recent study indicated that 51 percent of time away from port is devoted to actual fishing operations using 70 percent of the total fuel consumed.

BACKGROUND

Shrimp are the most valuable fishery product in the United States. In 1979, approximately 336 million pounds heads-on weight, with a dockside value of nearly $472 million, were landed at U.S. ports(1). In 1979, this fishery accounted for 60 percent of the volume and 80 percent of the value of product landed (2).

These impressive statistics do not reflect the economic stress that has been placed on the Gulf of Mexico shrimp fishery by rapidly increasing fuel prices, fluctuating harvest, and the general economic downturn which has resulted in unstable ex-vessel prices for shrimp. Spiraling fuel prices are devastating because of the extreme energy dependence of the Gulf shrimp fishery. Based on 1978 prices, a recent evaluation of cost and returns to shrimp fishermen in Louisiana indicated fuel and oil accounted for 40 to 54 percent of the operating costs of vessels over 50 ft.(3). Vessels of this size and larger comprise the bulk of the region's fleet. The impact of fuel prices was particularly severe in 1980-1981, with prices doubling. During February 1979, diesel fuel prices ranged from $0.43 to $0.52/gal. By February 1980, these prices had jumped to $0.79 to $1.00/gal.(4). By mid 1981, prices ranged from $1.14 to $1.26/gal. Swartz and Griffin, (5) based on 1978 cost and returns for a 75 ft. steel hull shrimp boat, suggested that as the price of fuel reached $0.90 per gal., the vessel owner began to operate at a loss of $0.01 per pound.

The Gulf Coast fleet consumed 33 percent of the diesel fuel used by the U.S. fishing fleet in 1978 (6); the shrimp fishery is second only to the Maine lobster fishery in energy inefficiency per unit of protein produced (7). By comparison the Gulf shrimp fishery is estimated to be two orders of magnitude more energy intensive than the Oregon shrimp fishery. In terms of energy consumption per unit of protein output, the Oregon fishery requires 3.6 Kcal energy input per Kcal protein output, while the Gulf fishery requires 198 Kcal (8). The high energy consumption level not only jeopardizes the economic viability of this industry but contributes to the economic drain placed on the nation due to increased fuel imports.

Mississippi and Alabama are typical of Gulf and South Atlantic states where shrimp play a major role in coastal economics. Shrimp accounted for 94 percent of the approximately $50 million value of Alabama seafood landings during 1979. Shrimp landings make up a somewhat smaller portion of the $33.3 million in landings in Mississippi; the processing industry depends upon shrimp, which it imports from other Gulf states. Of the 700 employed in Mississippi's seafood industry, approximately 60 percent are employed directly in shrimp processing. Seasonally, the seafood processing industry employs over 2000 and 1400, respectively (1,9). Shrimp boats are also major employers. There were over 623 documented vessels of more than five (5) tons gross capacity in the Alabama fleet in 1978 (10), and 625 shrimp boats over 45 ft. in length shrimped Mississippi waters in 1979 (11).

The shrimp fleet is characterized by a variety of vessels, which represent the major types of documented shrimp vessels found throughout the Gulf and South Atlantic regions. In general, three types are present. The first type is the 30-45 ft. "Biloxi-type" stern cabin vessel that dominated the fishery until the mid 60's.

The second type is the medium-size vessel of 50-65 ft. which is generally wooden with a forward cabin and is referred to as "the Florida-type" vessel. These vessels tend, for the most part to fish in the bays or near-shore Gulf. The third type of vessel range, from 65-85 ft., is generally made of steel, although there are a number made of fiberglass and wood (12). These offshore boats utilize the largest propulsion systems and are referred to as "Gulf boats" or "slabs."

Bay shrimpers work primarily inside the barrier islands. From the barrier islands to several miles offshore, medium-size vessels shrimp from June through December. Frequently, the slabs work distant waters on both the eastern side of the Mississippi River and off the Louisiana coast from the Mississippi River to Texas, as well as, the southwest coast of Florida.

During the off-season months Gulf shrimpers--at least in the past--have been able to maintain a low level operation by shrimping in off shore areas, or by going to southern Florida for pink shrimp (February to April). Because of unstable prices, low catch rates, and high fuel prices, many shrimpers were forced to tie up their boats for several months. Income could not offset increased operating costs resulting from higher fuel prices.

Fossil fuel both directly and indirectly affects the productivity of the nation's fisheries. The Gulf of Mexico shrimp fishery is among the most vulnerable of these fisheries. Fuel price increases, supply uncertainties, and the related spiraling cost of capital equipment, maintenance, and financing are expected to worsen rather than improve in future years. If greater fuel efficiency cannot be developed through fuel management techniques and new technological innovations, a major economic upheaval can be expected in the shrimping industry; one that is likely to cause significant economic loss and hardship to fishermen and processors as well, and change the structure of the industry.

Fleet Operating Characteristics of Upper Gulf Vessels

The shrimping year typically begins for Gulf vessels in mid-May when the first season opening occurs in Louisiana. Bay boats and the medium size vessels frequently migrate to Louisiana during the first few months of the shrimping year to catch brown shrimp in inshore waters. By mid-June, they will return to home ports as local shrimp seasons begin. Large Gulf boats may also participate in these fisheries, but the limitations placed on them by state laws put them at a distinct disadvantage. For example, both Mississippi and Alabama law allows only a 50 ft. headrope limit on vessels trawling in state waters.

During the months of July and August, bay boats typically work the inside state waters. In the fall months there is a seasonal catch in inland and offshore waters of white shrimp. The larger Gulf boats, and to a lesser extent transitional-size vessels, move to the beach areas as shrimp migrate offshore. In the summertime the fleet generally drifts to the south and west. There are a number of vessels in the Gulf that do not go west of the Mississippi River; however, the bulk of the offshore fleet moves into the area around the mouth of the Mississippi River and tends to move further and further west toward Texas as the fall months progress. As Christmas approaches, the Gulf boats work their way back to their homeports. Christmas generally signifies the end of the year's shrimping season.

During the peak season, boats working along the Louisiana and Texas coast may make runs back to home port or may unload at Louisiana ports. This has become a particularly common practice as fuel costs have risen and forced the fleet to reduce the number of trips to their homeport. During January, February, March, and early April, the fleet scatters along the Louisiana coast or moves to Florida's pink shrimping grounds from Tampa Bay south to Keywest, Florida.

Gulf boats work from the barrier island beaches offshore throughout the Gulf. The gear used by these vessels is unrestricted and is limited only by vessel power.

Characteristics of the Gulf and South Atlantic Fishing Fleet

The trend in the construction of fishing vessels, and in particular shrimp vessels, in the last several decades has been towards larger and more powerful vessels. Of the documented vessels, fishing in the Gulf and South Atlantic as of 1980, 3541 vessels or 31 percent of the fleet, were built prior to 1960, with 5596 vessels or 49 percent built after 1970 (Table I). Of vessels built prior to 1959 for composite fleet of the Gulf and South Atlantic, 80 percent had less than 100 horsepower; however, for the vessels built between 1960 and 1969, only 39 percent had less than 100 horsepower, with 34 percent having 200-299 horsepower and 52 percent having 100-300 horsepower. Vessels having more than 300 horsepower accounted for slightly more than eight (8) percent of the vessels constructed during this time period. For vessels constructed after 1970, only 24 percent had less than 100 horsepower, while 40 percent had 200-300 horsepower, and 59 percent had 100-300 horsepower. Seventeen (17) percent of the vessels constructed during this time period had horsepowers exceeding 300.

Analysis of the the Gulf and South Atlantic separately gives similar indications (Table II). As of December, 1980, 8374 documented vessels existed in the Gulf fishing fleet, of these, 30 percent or 2532 vessels, were built prior to 1959, with 4128 vessels or 49.3 percent built after 1970. The remainder of the vessels, 1682

TABLE I. ANALYSIS OF HORSEPOWER AS A FUNCTION OF AGE INCLUDING NUMBER OF VESSELS, PERCENT OF FLEET TOTAL AND PERCENT OF AGE GROUP FOR ALL PORTS IN THE GULF AND SOUTH ATLANTIC.

	VESSEL AGE													
HORSEPOWER	UNKNOWN			PRE-1959			1960-1969			POST 1970			TOTAL	
Less 100	45 1/	74 2/	.40 3/	2844 1/	80 2/	25 3/	845 1/	39 2/	7 3/	1364 1/	24 2/	12 3/	5098 1/	45 3/
100-199	6	10	.05	411	12	4	404	18	4	1064	19	9	1885	17
200-299	4	7	.04	143	4	1	738	34	7	2212	40	20	3097	27
300-399	1	2	.01	64	2	1	94	4	1	405	7	4	564	5
400-499	3	5	.03	17	<1	<1	40	2	<1	273	5	2	333	3
500-599	2	3	.02	18	<1	<1	14	<1	<1	144	3	1	178	2
600-699	-	-	-	6	<1	<1	6	<1	<1	66	1	<1	78	<1
700 ≥	-	-	-	38	1	<1	45	2	<1	68	1	<1	151	1
TOTAL	61		.54	3541		31.11	2186		19.20	5596		49.16	11384	

1/ Total number of vessels in the given horsepower range and constructed during the specified time period.

2/ Percent of total vessels constructed during the time period having the specified horsepower.

3/ Percent of total vessels having the designated horsepower.

TABLE II. ANALYSIS OF HORSEPOWER AS A FUNCTION OF AGE INCLUDING NUMBER OF VESSELS, PERCENT OF THE GULF FLEET, AND PERCENT OF AGE GROUP FOR ALL PORTS IN THE GULF.

	VESSEL AGE													
HORSEPOWER	UNKNOWN			PRE-1959			1960-1969			POST 1970			TOTAL	
Less 100	25 1/	78 2/	.30 3/	2091 1/	83 2/	25 3/	704 1/	42 2/	8 3/	1073 1/	26 2/	13 3/	3893 1/	47 3/
100-199	3	9	.04	246	10	3	284	17	3	698	17	8	1222	14
200-299	2	6	.02	101	4	1	552	33	7	1685	41	20	2340	28
300-399	1	3	.01	39	2	<1	64	4	<1	315	8	4	419	5
400-499	0	0	.00	9	<1	<1	24	1	<1	179	4	2	212	3
500-599	1	3	.01	14	1	<1	9	<1	<1	89	2	1	113	1
600-699	0	0	.00	3	<1	<1	4	<1	<1	48	1	<1	55	1
≤700	0	0	.00	29	1	<1	41	2	<1	50	1	<1	120	1
TOTAL	32		.38	2532		30.24	1682		20.09	4128		49.30	8374	

1/ Total number of vessels in the given horsepower range and constructed during the specified time period.

2/ Percent of total vessels constructed during the time period having the specified horsepower.

3/ Percent of total vessels having the designated horsepower.

or 20 percent, were built during the 1960-69 time period. An analysis of horsepower of these vessels as a function of time yields an expected result. For vessels built prior to 1960, 83 percent had less than 100 horsepower and 93 percent had less than 200 horsepower. For vessels built during the 1960-69 era, only 42 percent had less than 100 horsepower, while 33 percent had 200-299 horsepower, 92 percent had 300 horsepower or less. As compared with those built prior to 1960, this represents a several fold increase in propulsion capacity.

For vessels built during 1970 or after, only 26 percent had less than 100 horsepower, while 41 percent had 200-299 horsepower. Ninety-two (92) percent of the vessels had 400 horsepower or less. By comparison, two horsepower ranges, i.e., less than 200 horsepower, accounted for 93 percent of the pre-1960 fleet, while three (3) horsepower ranges accounted for 92 percent of the 1960-69 constructed fleet and four (4) horsepower ranges accounted for 92 percent of the post-1970 construction. A composite of the fleet as it existed in late 1979 indicates that approximately 47 percent has less than 100 horsepower, with 28 percent of the fleet having 200-299 horsepower. Slightly more than nine (9) percent of the fleet had 300 or more horsepower.

Table III indicates growth in the South Atlantic fishing fleet that parallels that of the Gulf fleet. As of December 1980, 3010 vessels existed in the fleet. Of these, 1009 were built prior to 1960 and comprised 33.5 percent of the total fleet. Vessels built after 1970 comprised 48.77 percent of the fleet (1468 vessels). Of vessels built prior to 1960, 75 percent had less than 100 horsepower, with 91 percent having less than 200 horsepower. For vessels built in the 1960-69 period, only 28 percent had less than 100 horsepower, as compared with 75 percent for the pre-1959 period. For this time period, 24 percent had 100-199 horsepower and 37 percent had 200-299 horsepower. The vessels of less that 300 horsepower accounted for 89 percent of all vessels constructed for the 1960-69 time period.

Vessels constructed during 1970 and after, accounted for 48.77 percent of the entire South Atlantic fleet. Of these vessels, only 20 percent had 100 horsepower or less, with 26 percent having 100-199 horsepower, and 36 percent having 200-299 horsepower. These three horsepower ranges, i.e., 0-300 horsepower, accounted for 82 percent of the vessels constructed post-1970.

For the Gulf fleet, 30.24 percent of the fleet was constructed prior to 1960, while 33.52 percent of the South Altantic fleet was constructed prior to 1960. For the South Atlantic fleet, 48.77 percent of the fleet was constructed post-1970, while 49.3 percent of the Gulf fleet was constructed post-1970. Observations of Tables II and III indicate a more rapid movement toward larger engines in the South Atlantic than in the Gulf, although not at a substantially greater rate.

TABLE III. ANALYSIS OF HORSEPOWER AS A FUNCTION OF AGE INCLUDING NUMBER OF VESSELS, PERCENT OF ATLANTIC FLEET TOTAL, AND PERCENTAGE OF AGE GROUP FOR ALL PORTS IN THE SOUTH ATLANTIC.

	VESSEL AGE														
HORSEPOWER	UNKNOWN			PRE-1959			1960 -1969			POST 1970			TOTAL	
Less 100	20 1/	69 2/	.66 3/	753 1/	75 2/	25 3/	141 1/	28 2/	5 3/	291 1/	20 2/	10 3/	1205 1/	40 3/
100-199	3	10	.10	165	16	6	120	24	4	375	26	13	663	22
200-299	2	7	.07	42	4	1	186	37	6	527	36	18	757	25
300-399	0	0	.00	25	2	1	30	6	1	90	6	3	145	5
400-499	3	10	.10	8	1	<1	16	3	<1	94	6	3	121	4
500-599	1	3	.03	4	<1	<1	5	<1	<1	55	4	2	65	2
600-699	0	-	.00	3	<1	<1	2	<1	<1	18	1	<1	23	<1
≥ 700	0	0	.00	9	1	<1	4	<1	<1	18	1	<1	21	1
TOTAL	29		.96	1009		33.52	504		16.74	1468		48.77	3010	

1/ Total number of vessels in the given horsepower range and constructed during the specified time period.

2/ Percent of total vessels constructed during the time period having the specified horsepower.

3/ Percent of total vessels having the designated horsepower.

One method of looking at the rate of increase in power for the Gulf and South Atlantic fleet is by comparing vessel horsepower with vessel length. Table IV is an analysis of the composite Gulf and South Atlantic fleet showing horsepower as a function of vessel length. Of the 11,384 vessels comprising the Gulf and South Atlantic fleet, 6993 or 61.43 percent are less than 55 ft., with vessels of 55-64 ft. comprising 13.11 percent of the fleet, vessels 65-74 ft. in length comprising 20.63 percent of the fleet, and vessels 75-84 ft. comprising 3.15 percent of the fleet. Of vessels less that 55 ft. in length, 65 percent have less than 100 horsepower, while 85 percent have less than 200 horsepower and 94 percent less than 300 horsepower. For vessels in the 54-64 ft. category, 36 percent have 100 horsepower or less, with 35 percent having 200-299 horsepower. For vessels in the 65-74 ft. category, 78 percent have engines with horsepower in 200-299 horsepower category. For vessels 75-84 ft., 28 percent have 200-299 horsepower, 31 percent have 300-399 horsepower, and 19 percent have 400-499 horsepower. Of the 75-84 ft. category vessels, 78 percent have between 200-500 horsepower. Of vessels greater than 84 ft. in length, 60 percent have 700 or more horsepower, while a full 80 percent have 500 or more horsepower.

Tables V and VI again indicate remarkable similarities between the Gulf and South Atlantic fleets when one compares an analysis of horsepower as a function of vessel length for the two fleets, with a possible exception being a more rapid growth in the Gulf of vessels in the 65-74 ft. length category. For the 3010 vessels in the South Atlantic fleet, some 66 percent were less than 55 ft. in length with 15.05 percent being 55-64 ft., 15.08 percent being 65-74 ft. in length, and 2.39 percent being 75-84 ft. in length. Of the vessels less than 54 ft. in length in the South Atlantic fleet, 53 percent had less than 100 horsepower, 79 percent had less than 200 horsepower, and 90 percent had less than 300 horsepower. For vessels in the 55-64 ft. category, 29 percent had less than 100 horsepower, while 37 percent had 200-299 horsepower, a significant increase over vessels less than 10 ft. shorter. For vessels 65-74 ft. in length, only 2 percent had less than 100 horsepower and 10 percent had less than 200 horsepower, 76 percent of this length category had 200-299 horsepower. For vessels in the 75-84 ft. category, 72 percent had 200-500 horsepower, while 82 percent had 200-600 horsepower. For vessels greater than 85 ft. in length, 30 percent had 700 horsepower or more, with the remaining 70 percent relatively evenly distributed among the remaining horsepower ranges.

Of the 8374 vessels existing in the Gulf fishing fleet, 4999 or 59.7 percent, were less than 54 ft. in length, while 12.42 percent of the vessels were 55-64 ft., 22.63 percent were 65-74 ft. in length, and 3.43 percent were 75-84 ft. in length. For vessels less than 55 ft. in length, 69 percent had less than 100 horsepower, 87 percent

TABLE IV. ANALYSIS OF HORSEPOWER AS A FUNCTION OF VESSEL LENGTH INCLUDING NUMBER OF VESSELS, PERCENT OF TOTAL FLEET AND PERCENT OF VESSELS IN DESIGNATED SIZE GROUP FOR ALL PORTS IN THE GULF AND SOUTH ATLANTIC

	VESSEL LENGTH-FT																
HORSEPOWER	≤ 54			55 - 64			65 - 74			75 - 84			≥85			TOTAL	
100 or Less	4512 1/	65 2/	40 3/	537 1/	36 2/	5 3/	44 1/	2 2/	<1 3/	3 1/	1 2/	<1 3/	2 1/	1 2/	1	5098 1/	45 3/
100-199	1403	20	12	319	21	3	154	7	1	2	1	<1	7	4	<1	1885	17
200-299	632	9	6	522	35	5	1830	78	16	102	28	<1	11	6	<1	3097	27
300-399	200	3	2	67	4	<1	175	7	2	111	31	1	11	6	<1	564	5
400-499	121	2	1	27	2	<1	110	5	1	69	19	<1	6	4	<1	333	3
500-599	89	1	<1	10	1	<1	22	1	<1	34	9	<1	23	12	<1	178	2
600-699	18	<1	<1	3	<1	<1	14	1	<1	26	7	<1	17	9	<1	78	<1
700 ≥	18	<1	<1	8	<1	<1	0	0	0	12	3	<1	113	59	1	151	1
TOTAL	6993		61.43	1493		13.11	2349		20.63	359		3.15	190		1.67	11384	

1/ Total number of vessels in a given horsepower range and of the indicated vessel length.

2/ Percent of vessels of designated length having the specified horsepower - totals 100% for each category.

3/ Percent of total vessels in designated length horsepower category.

TABLE V. ANALYSIS OF HORSEPOWER AS A FUNCTION OF VESSEL LENGTH INCLUDING NUMBER OF VESSELS, PERCENT OF TOTAL FLEET AND PERCENT OF VESSELS IN DESIGNATED SIZE GROUPS FOR ALL SOUTH ATLANTIC PORTS

	VESSEL LENGTH - FT.																
HORSEPOWER	54			55 - 64			65 - 74			75 - 84			85			Total	
< 100	1063 1/	53 2/	35 3/	133 1/	29 2/	4 3/	8 1/	2 2/	<1 3/	0 1/	0 2/	0 3/	1 1/	3 2/	<1 3/	1205 1/	40 3/
100-199	518	26	17	104	23	3	35	8	1	1	1	<1	5	14	<1	663	22
200-299	218	11	7	169	37	6	347	76	12	19	26	<1	4	11	<1	757	25
300-399	79	4	3	22	5	<1	24	5	<1	15	21	<1	5	14	<1	145	5
400-499	62	3	2	13	3	<1	25	5	<1	18	25	<1	3	8	<1	121	4
500-599	39	2	1	5	1	<1	11	2	<1	7	10	<1	3	8	<1	65	2
600-699	7	<1	<1	1	<1	<1	4	1	<1	6	8	<1	5	14	<1	23	<1
≥ 700	8	<1	<1	6	1	<1	0	0	0	6	8	<1	11	30	<1	31	1
TOTAL	1994		66.25	453		15.05	454		15.08	72		2.39	37		1.23	3010	

1/ Total number of vessels in a given horsepower range and of the indicated vessel length.

2/ Percent of vessels of designated length having the specified horsepower - totals 100% for each category.

3/ Percent of total vessels in designated length horsepower category.

TABLE VI. ANALYSIS OF HORSEPOWER AS A FUNCTION OF VESSEL LENGTH, INCLUDING NUMBER OF VESSELS, PERCENT OF TOTAL FLEET, AND PERCENT OF VESSELS IN THE DESIGNATED SIZE GROUP FOR ALL PORTS IN THE GULF

	VESSEL LENGTH - FT.																
HORSEPOWER	54			55 - 64			65 - 74			75 - 84			85			Total	
<100	3449 1/	69 2/	41 3/	404 1/	39 3/	5 3/	36 1/	2 3/	<1 3/	3 1/	1 3/	<1 3/	1 1/	<1 2/	<1 3/	3893 1/	46 2/
100-199	885	18	11	215	21	3	119	6	1	1	<1	<1	2	<1	<1	1222	15
200-299	414	8	5	353	34	4	1483	78	18	83	29	1	7	4	<1	2340	28
300-399	121	2	1	45	4	<1	151	8	2	96	33	1	6	4	<1	419	5
400-499	59	1	<1	14	1	<1	85	4	1	51	18	<1	3	2	<1	212	3
500-599	50	1	<1	5	<1	<1	11	1	<1	27	9	<1	20	13	<1	113	1
600-699	11	<1	<1	2	<1	<1	10	1	<1	20	7	<1	12	8	<1	55	<1
≥ 700	10	<1	<1	2	<1	<1	0	0	0	6	2	<1	102	67	1	120	1
TOTAL	4999		59.70	1040		12.42	1895		22.63	287		3.43	153		1.83	8374	

1/ Total number of vessels in a given horsepower range and of the indicated vessel length.

2/ Percent of vessels of designated length having the specified horsepower - totals 100% for each category.

3/ Percent of total vessels in designated length horsepower category.

had less than 200 horsepower, and 95 percent had less than 300 horsepower. For vessels in the 55-64 ft. length category, only 39 percent had less than 100 horsepower, while 34 percent had 200-299 horsepower, 94 percent had less than 300 horsepower. For vessels in the 65-74 ft. category, 78 percent had 200-299 horsepower, while 86 percent had 200-400 horsepower. For vessels in the 75-84 ft. category, 29 percent had 200-299 horsepower, 33 percent had 300-399 horsepower, and 18 percent had 400-499 horsepower. For vessels greater than 85 ft. in length, 67 percent had more than 700 horsepower, with the remaining vessels relatively evenly distributed among the remaining horsepower ranges.

An analysis of the fishing fleet in the Gulf and South Atlantic divided into five year increments for construction date, yields insightful information into relative growth and magnitude of vessel sizes, Table VII. For vessels constructed prior to 1959, the mean length was 43.68 ft. Mean length continued to increase to a maximum of 55.78 ft. for vessels constructed during the 1965-69 time period. Beginning in 1970, a sharp downturn to 51.38 ft. occured for vessels constructed during the 1970-74 time period, with slight increases noted to the present date. Overall vessel length of the fishing fleet existing in the South Atlantic and Gulf is 49.57 ft. Table VII and Figure 1 also give an indication of relative changes of mean horsepower per ft. of vessel length. For vessels constructed prior to 1959, mean horsepower per ft. of vessel was 3.72. This indicator of fishing power increased steadily from the 3.72 horsepower per ft. to a maximum of 6.76 horsepower per ft. for vessels constructed after 1980. As may be observed in Figure 1, this relationship approximates that of a straight line and is a rather dramatic indication of the rapid increase in power which exists in the Gulf fleet, and to a large part, may account for the high fuel consumption of the Gulf and South Atlantic fleet per unit of production.

Vessel Time Budget

The Mississippi-Alabama Sea Grant Consortium, National Marine Fisheries Service, and Gulf and South Atlantic Fisheries Development Foundation funded a project to include analysis of time and energy budgets for the Gulf shrimp fleet (18). The total number of trips was 119; trip length ranged from 6 hours to 17 days.

Vessel activities for which time was recorded included:

WU	Engine warm up
PF	Travel time from port to first fishing ground
FP	Travel time from last fishing ground to port
FF	Travel time between fishing grounds
LT	Unproductive time - main propulsion unit not running

TABLE VII. VESSEL CHARACTERISTICS AS A FUNCTION OF CONSTRUCTION DATE FOR THE GULF AND SOUTH ATLANTIC FLEET

	CONSTRUCTION DATE							
	Unknown	Pre-1959	1960-1964	1965-1969	1970-1974	1975-1980	Post 1980	Total
No. of Vessels	61	3541	694	1492	1896	3098	602	11384
Mean Vessel Length	38.71	43.68	50.55	55.78	51.38	51.62	52.49	49.57
Mean Vessel Horsepower	176.93	162.54	231.91	290.44	290.47	324.66	355.05	259.22
Mean Horsepower/ft.	4.56	3.72	4.58	5.20	5.65	6.28	6.76	5.22

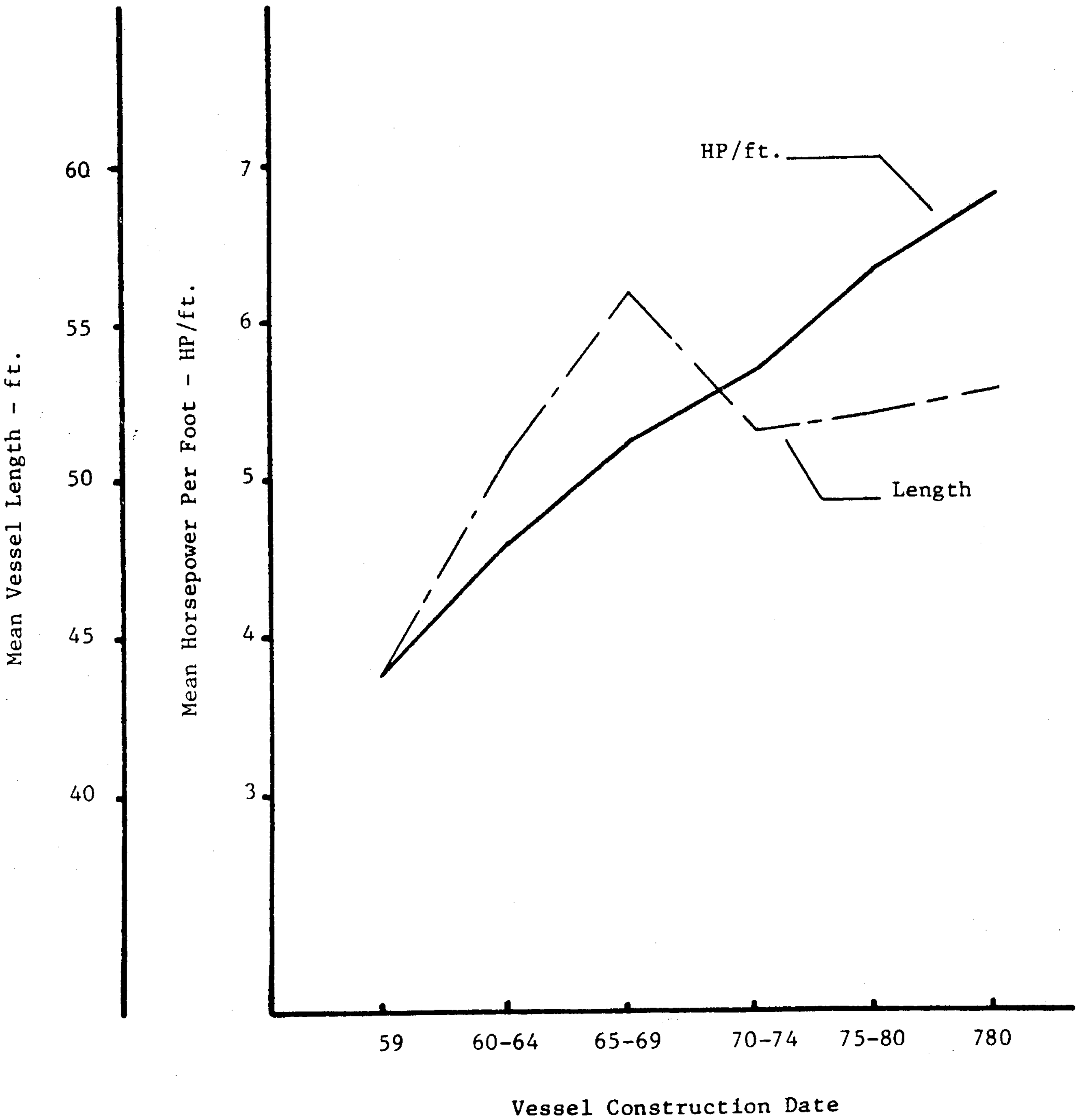

FIGURE I MEAN VESSEL LENGTH AND HORSEPOWER PER FOOT AS A FUNCTION AT CONSTRUCTION DATE.

PT	Pick-up time--time spent picking up and putting out gear
FO	Time spent pulling try-trawl only
F1	Time spent pulling one net
F2	Time spent pulling two nets
F4	Time spent pulling 4 nets - quad trawls

Table VIII is a composite of all trips taken by all vessels in the study. Total travel time to and from port amounted to 12.2 percent of total time away from port. The inclusion of time spent traveling between fishing grounds brings total unproductive operating time to 18.7 percent. A total of 51.9 percent of time was devoted to fishing with one or more trawls. Nearly twice as much time was spent with traditional gear (two trawls) as was spent with quad trawls. Approximately 25 percent of the total time was spent laying-to i.e., without propulsion units running.

Table VIII Vessel Activity Analysis as a Function of Trip Length

Total Time		Time Percent 2/				
			Trip Length - days			
Act. 1/	Hrs.	Composite	0-2	2-4	4-7	7
WU	156.97	2.3	2.1	1.6	7.4	0.5
PF	397.00	5.7	11.9	9.7	4.8	3.2
FF	451.18	6.5	16.7	6.7	6.3	3.3
FP	452.50	6.5	2.4	3.0	4.3	9.1
LT	1750.65	25.2	5.6	25.6	25.8	30.4
PT	62.27	0.9	---	0.7	0.5	1.4
FO	74.08	1.1	0.6	4.2	0.6	0.8
F1	11.18	0.2	0.3	0.2	---	0.2
F2	2546.45	36.6	60.4	30.0	40.2	29.6
F4	1053.98	15.1	---	18.3	10.1	21.4
F2&F4			60.4	48.3	50.3	51.0
TOTAL	6959.99					

1/ See definition of activity elsewhere in document.
2/ Percent of time devoted to each activity of all trips in that time range for all vessels.

For trips of two days or less approximately 10 percent more time is spent fishing than in other trip lengths. During the two day trip little time is spent laying-to; more time is spent traveling to and from port.

As trip length increased, travel time to and from ports decreased from 28.6 percent for two day trips, to 6.5 percent for trips 7 days or more. Trade-offs are thus being made between decreased fishing time and travel time to and from port.

Time devoted to fishing is uneffected by trip length for trips of more than two days. As trip length increases travel time between fishing grounds increases from a low of 2.4 percent for the two day trip to 9.1 percent for the seven day trip. Time spent devoted to fishing is uneffected by trip length except for the two day trip.

Vessel Energy Budget

During late 1980 and early 1981, three vessels were equipped with Avicon fuel flow and tachometer systems. Because of limited data only limited inferences may be drown from fuel consumption data collected. Vessel parameters are shown below.

Vessel A

length	19.2m (63 ft)
Hp-continuous	275 @ 1800 rpm
gear reduction	4.5:1
wheel	
blades	5
pitch	96.5 cm (38 in)
diameter	127.0 cm (50 in)

Vessel B

length	25.9m (85 ft)
Hp-continuous	520 @ 1800 rpm
gear reduction	6:1
wheel	
blade	4
pitch	
diameter	
nozzle	yes

Vessel C

length	22.9m (75 ft)
Hp-continuous	365 @ 1800
gear reduction	6:1
wheel	
blade	4
pitch	122cm (48 in)
diameter	167cm (66 in)

As part of an ongoing study, three vessels have been equipped with fuel flow monitors. Table IX indicates a great deal of variation in fuel consumption patterns. It is difficult to draw conclusions from such limited data; however, some general observations may be made.

The largest percentage of the fuel is used in the actual fishing operations (64-74 percent). Of the vessels which used both two and four trawls, the use of four trawls was more fuel efficient than the use of two. A careful evaluation of net construction would indicate that less webbing is used in four small nets than in the two large nets. Catch information is insufficient to draw conclusions; however, other studies indicate little overall difference between dual trawls and quad trawls.

Fuel consumption, when using two trawls, was 62.5 l/hr (16.5 gal/hr); the use of quad trawls decreased fuel consumption to 51.1 l/hr (13.5 gal/hr). With no apparent catch difference this decrease could be significant over a fishing season.

Vessel B, with its larger engine used nearly 70 percent more fuel than vessel C, yet operated only 74 hours more than vessel C. Little difference is evident in catch data for vessels B & C.

Operational differences between vessels B & C are also present. While both are owner-operated, the visual state of repair for B was much poorer than for C.

Assuming fuel cost at $1.20 per gal., Vessel A incurred a total fuel cost of $7.20 per hour away from port as compared to $19.45 per hour for Vessel B and $13.20 per hour for Vessel C. Expenses of B compared to A were 270 percent greater while C compared to A was 183 percent greater. Using Vessel A as a base, Vessel C must catch nearly twice as much shrimp to pay expenses as Vessel A, while Vessel B must nearly triple catch as compared to Vessel A.

Prior discussions provide an insight only into gross efficiency. Evaluating operating costs in dollars per horsepower hour--obtained by dividing fuel cost per hour by continuous horsepower--provides an entirely different view. Cost for Vessel A with 275 hp are $.026 per hp-hr while cost for Vessels B and C with 520 and 365 hp respectively are 0.037 and $0.036 per hp-hr. Thus, while gross efficiency for B and C are significantly different, cost per mhp differ insignificantly.

If it is assumed that a typical trip is 255 hours in length (10.6 days), the need for prior planning becomes obvious. For Vessel A, travel time to and from port would cost $496 per trip. Comparable expenses for Vessel B would be $850 per trip and $473 per trip for Vessel C.

Table IX Fuel Consumption Summary

Vessel Act. 2/	Vessel A 1/ Time % 3/	Fuel % 4/	Fuel Rate 1/hr	gal/hr	Vessel B 5/ Time % 3/	Fuel % 4/	Fuel Rate 1/hr	gal/hr	Vessel C 6/ Time % 3/	Fuel % 4/	Fuel Rate 1/hr	gal/hr
WU	1	--	--	--	1	--	--	--	1	--	--	--
PF	7	12	51.1	13.5	7	8	73.8	19.5	7	7	58.7	15.5
FP	8	15	51.1	13.5	7	9	66.2	17.5	4	7	54.8	14.5
FF	4	8	43.5	11.5	3	5	89.0	23.5	10	13	32.2	8.5
LT	47	--	--	--	27	--	--	--	24	--	--	--
PT	2	1	5.7	1.5	5	2	32.2	8.5	3	2	13.3	3.5
FO	--	--	--	--	--	--	--	--	4	2	36.0	9.5
F2	30	64	47.3	12.5	--	--	--	--	9	15	62.5	16.5
F4	--	--	--	--	52	74	92.7	24.5	39	54	51.1	13.5
F2 & F4									48	69	--	--

1/ Total operating hours - 255.4
Total fuel consumption - 5802 l (1533 gal.)
2/ Vessel activity code defined previously
3/ Percent of total time of vessel
4/ Percent of total fuel used for designated activity
5/ Total operating hours - 591.4
Total fuel consumption - 9587 gal.
6/ Total operating hours - 517
Total fuel consumption - 5688 gal.

Time spent traveling to and from port for the three vessels ranged from 11 to 14 percent of total time away from the dock. This accounted for 14-27 percent of the total fuel used. A comparison of fuel consumption per hour indicates the fleet is already adjusting to high fuel cost. In every case, fuel consumed per hour during "running" is near that used while working.

Economics of Fuel Consumption

If we were to assume the technology, either sail-assist or otherwise, has been developed which will allow a 50 percent reduction in fuel costs while traveling between fishing grounds or between fishing grounds and ports, then we might expect for an 85 ft. vessel (Vessel B) an annual fuel savings of 8700 gallons or an annual cost savings of $10,400 per year, based upon $1.20 per gallon diesel fuel. Similar computations for a 75 ft. vessel (Vessel C) will yield an annual fuel saving of 5500 gallons, or an annual cost savings of $6600, again based upon a 50 percent reduction in fuel used in traveling and $1.20 per gallon fuel. Similarly, a 100 percent reduction in fuel used in traveling, for example, full utilization of sail during these activities, would result for an 85 ft. vessel in an annual fuel savings of 17,400 gal., with an annual cost savings of $20,900, based upon $1.20 per gallon fuel. For a 75 ft. vessel, an annual fuel savings, based upon 100 percent reduction in fuel used in traveling, would yield an 11,100 gallon savings in fuel usage and a related $13,400 savings in cash outlay.

It is obvious that the income of commercial shrimping vessels is directly related to hours spent with nets actively fishing in the water. Thus, technologies applicable to the actual trawling must be carefully selected. If we could assume technology which would reduce fuel consumption during trawling by 10 percent, then we might expect the following savings. For an 85 ft. vessel (Vessel B), we might expect a 6000 gallon per year reduction in fuel consumption with a comparable $7200 savings in cash outlay, based upon $1.20 fuel. For a 75 ft. vessel pulling double trawls and achieving a 10 percent reduction in fuel savings while trawling, we would expect an annual reduction in fuel consumption of 4000 gallons, with an annual cost savings of $4800. Because the demonstrated fuel efficiency of quadtrawls, that same vessel would reduce its fuel consumption by 3300 gallons and realize an annual fuel savings of $4000.

For sail-assist to be fully useful in the Gulf and South Atlantic fishing fleet the author recommends the following for consideration:

1) Sails must be adaptable to existing vessels and must preferably be located on the bow or off the stern.
2) If used in vessel travel, sails must help maintain a speed of 7.5 to 9 knots, with the displacement hulls currently in use.

3) If used in trawling, sails must
   a) not produce lateral drift,
   b) not affect vessel draft,
   c) operation must not decrease catch, even if cost effective,
   d) should allow for rapid maneuverability of the vessel,
   e) should develop a pull of 6000-7000 pounds for the typical 70-80 ft. vessel, and
   f) sails must be designed so that rapid knockdown can occur in an almost instantaneous fashion.

While the author is not a naval architect nor a marine engineer, he does not see the utilization of sail-assist as becoming wide spread in the Gulf and South Atlantic shrimp fleet in the near future, unless innovative approaches to sail utilization occur. The continuing design of high-efficiency simplified sail-assist systems may of course change that future.

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SRI LANKA'S EXPERIENCE TO DATE WITH SAIL ASSISTED FISHING BOATS

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ABSTRACT

In Sri Lanka, traditional craft, sailing and non-sailing, were used in the marine fishery up to 1950.

The need to introduce modern fishing craft capable of working with more fishing gear was felt at this time.

The decade 1950-1960 saw the gradual mechanization of the traditional craft and the introduction of the mechanized fishing boat. Consequently, by the mid-seventies, a major part of Sri Lanka's fishing fleet depended on expensive fuel.

As fuel costs kept on escalating, the need to increase fuel efficiency and adopt fuel saving measures became imperative.

The era of sail-assisted low powered mechanized fishing boats then dawned and the construction of such craft is in progress since.

TRADITIONAL CRAFT: FISHING FLEET BEFORE 1950

Sri Lanka's traditional craft consisted of dugouts, with or without outrigger, log rafts, and planked craft using sail or rowing.

DUGOUT (ORU):

This is narrow outrigger sailing craft and comes in varying lengths from 15' to 36'. The smaller craft fish in protected waters using rod and line, cast nets, or small mesh drift net and are rowed.

The larger craft are used for hand lining, drift gill netting, trolling, trawling, pole and line fishing. They fish up to the perimeter of the continental shelf using a large square sail giving very high downwind power. Two bamboo masts about 30 feet (9 m) long control the two upper corners of the square sail. The Oru can achieve a speed of about 10 knots. When winds fail, or in certain seasons when there is no wind, the craft is rowed for periods up to 10-12 hours which leaves only 1-2 hours for actual fishing. By the end of 1950 it was believed that the Oru had reached the limit of its development.

DUGOUT (VALLAM OR THONI):

This fishing craft with or without outrigger, is of dug out or planked construction in the case of large craft. The small craft are used in lagoons or close to shore employing mainly rod and line, cast nets, and small mesh drift netting.

The planked vallam is a larger version of the dug out vallam. It is a narrow and long craft with frames and a keel of varying length from 20'-40' (6-12 m). They are rowed or operated with a small sail and fish within 8-lo miles from shore using hand lining, and drift and gill netting.

PLANKED CRAFT (PARU OR PADAKU):

These are flat-bottomed stitched planked broad boats of 30'-40' (9-12 m.) in length. They are used mainly for beach seining within a distance of about 1-2 miles from the shore. Most of them are rowed while some use an outrigger and sail. The latter fish up to 10 miles from the shore.

THE LOG RAFT (TEPPAM OR KATTUMARAM):

The 12'-18' (3.6-5.5 m.) long raft were called "Teppam" while its 14'-30' (4.3-9.1 m.) version was known as "Kattumaram". These craft fish up to 10-12 miles from the shore using small mesh drift gill nets. Most of the small rafts are paddled while some use a square sail. The larger Kattumaram uses a triangular sail.

The body of the raft is formed of three centre logs and two shorter logs, one on each side with a three-piece shaped prow at the front end. These logs are fastened together into position by two wooden strips at fore and aft and lashed.

Annex A gives the number of traditional craft in operation in 1951 and 1952.

MECHANIZATION OF THE TRADITIONAL CRAFT AND
THE INTRODUCTION OF THE MECHANIZED FISHING BOAT

According to the 1951 Administrative report of the Sri Lankan Acting Director of Fisheries, the local builders of the Dugout outrigger canoe (oru) were of the view that the use of an outboard motor on an oru would not present any problems. In their opinion it would enable the reduction of a great deal of top weight by the elimination of the use of sails and the use of much smaller outriggers. A number of fishermen were of the view that an outboard motor which gives a 5 knot speed would be of greater advantage than a sail entails, particularly when changing tack.

At this stage, a batch of outboard motors was provided by the F.A.O. to be installed in the traditional craft. Mechanization continued in 1953. The F.A.O. Fishery Engineer installed three marine diesel engines supplied by the F.A.O. in three traditional craft from from the Northern part of the Island. The fishermen were very enthusiastic and they bought up all the available engines and placed orders for more. By the end of 1953, 14 traditional craft had been mechanized. Cost of fuel was not taken into reckoning during this initial stage and the mechanization of the traditional craft, dug-out, both outrigger and non outrigger, planked craft and log rafts with petrol or diesel outboard motors and inboard marine diesel engines continued progressively around the Island.

During this period, attention was focused on the stagnation in the local fishing industry. The need to introduce a modern fishing craft capable of using more fishing gear was felt essential.

Local fishing craft had hardly changed during the past century. On the west and south coasts the fishermen used the narrow dug-out sailing outrigger Canoe or Oru. When the winds failed or, in certain seasons when there is no wind, these craft were rowed to and from fishing grounds with 10-12 hours being spent on traveling and 2 or 3 hours of actual fishing possible at the grounds. Also, on the west coast the fishermen used the log raft Teppam or the larger log raft Kattumaram.

The Vallam, either Dug-out or planked construction, with or without outrigger, was used by the Northern fishermen. The large 30'-40' (9-12 m.) sailing craft of planked construction known as the "Padaku" were also used in the Northern waters for beach seine operations.

Another planked bottomed craft called the "Paru" was used for beach seine operation in the Northeast coast.

None of these craft in their original design was equipped with an engine.

The income from mechanized traditional craft showed a marked increase as against the non-mechanized craft. These craft used mechanized power to get out to the fishing grounds and back and this enabled them to get back to port when the market is at its best and the fish were in better condition on arrival than in the slower non-mechanized craft.

Further, the crews were able to work more days in the month and the number of actual fishing hours increased. The range of operation on these craft was wider particularly in calm weather when sailing boats cannot go far.

MECHANIZED BOAT:

Before the period referred to above, the fishermen had been seeking advice on the modern types of fishing vessels and gear suitable for their use. In their opinion the traditional craft were incapable of further development and the limitations in their size and range had prevented them from taking full advantage of the large shoals of fish which frequently appeared on grounds.

A mechanized fishing boat was built by a local building company for the Department of Fisheries in December 1958. Its dimensions were:

Length	-	24 ft. (7.3m)
Beam	-	8 ft. (2.4m)
Draft	-	2.5 ft. (76cm)
Engine	-	9 H.P. Deutz.

In 1959 the length of this boat was increased to 26 feet (7.9m) and cost of production worked out as follows:

Boat	-	Rs. 9,500	(US $413.00)
Engine	-	Rs. 5,000	(US $217.00)
Gear	-	Rs. 3,000	(US $130.00)
		Rs. 17,500	(US $760.00)

A loan scheme was inaugurated to boost the sale of these boats and the repayment period was limited to 5 years. Due to satisfactory operational results, the period of repayment was subsequently reduced to 3 years and a monthly installment of about Rs. 500/- was fixed.

From this time, the Sri Lanka fishing fleet was augmented primarily and rapidly by 28 feet (8.5m) mechanized boats. In addition, the mechanization of the traditional craft was continued. Cost of fuel during 1960-1970 did not constitute a major constraint in the mechanization program. Consequently, the fishermen were easily persuaded by the engine suppliers to install engines of a higher horsepower than that which had been hitherto in use, i.e. 9 H.P. - 15 H.P. on the premise that it would result in faster journies to and from the fishing grounds coupled with the ability to land prime quality fish. This propaganda had its desired effect in that 30-36 H.P. engines were the most common in use by the end of the decade in 1970 on the 28' boats.

Initially, these 28' boats were designed to accommodate engines of 9-15 HP rendering a speed in the region of 6 knots. Doubling the H.P. by the installation of 30-36 HP engines merely increased the speed by only about one knot as these boats were designed to achieve a speed of about 7 knots.

NEED TO INTRODUCE FUEL SAVING MEASURES

With the beginning of the 1970's, the contribution towards the national catch from beach seining, which was approximately between 30-40%, declined appreciably resulting in a near total dependency on the national fleet's production. Sri Lanka has been no exception to the fuel price hikes experienced by the world at large since the seventies, while a major part of its fleet entirely depended on imported oil for its effective operation. The need to introduce methods for conserving energy and achieving maximum fuel efficiency thus became paramount in the context of the cost component and national foreign exchange predicament.

WHY REVERSION TO SAIL ONLY IS NOT POSSIBLE:

Reversion to total dependency on sail is neither possible nor prudent for the following reasons:

* As the development of the sailing skill and design development of the sailing craft was abruptly arrested by the introduction of the mechanized craft there is a dearth of sailing boat skills among the fishermen.

* It would be futile to attempt to design a boat to achieve speed and to procure prime quality fish with the aid of sail only in the context of the present day competitive market and consumer demand.

* Exclusively sail propelled boats are not adaptable to modern technologies of economic fish harvesting.

MEASURES TAKEN TO INTRODUCE SAIL-ASSISTED FISHING:

A number of measures, both foreign aided and local, are under way with a view toward introducing sail-assisted fishing craft. Some of these important projects are:

* U.S.A.I.D. Sail-assisted fishing boat program

* F.A.O. Bay of Bengal Fishery Project

* A.D.B. Fishery Project

* The East Coast Fishery Development Project

* Sri Lanka Ministry of Fisheries Project

The U.S.A.I.D. Program entails the construction of 28 foot, 3½ ton G.R.P. boats equipped with 15 H.P. Volvo Penta diesel inboard engines and sail made locally with imported Dacron material and gaff cutter rigged. This program further involved the training of fishermen from selected areas in handling this particular type of sail rig. At present, a number of these boats have been issued to different fishing areas around the island and their performance is being monitored.

The F.A.O. Bay of Bengal Fishery Project in Sri Lanka is mainly concerned with the development of technology in respect to fishing craft, fishing gear and methods.

In mid-1981, a sail-assisted fishing boat called SRL - 11 was introduced under this project. This 26 foot (7.9m) boat is built of marine plywood, is G.R.P. sheathed and fitted with a Deutz 12.5 HP air-cooled onboard engine. The SRL 11 is equipped with a bermuda rig including main sail, jib and genoa, set in an aluminum mast. The boat is being tested for sea-faring ability and fishing capability in the west coast of Sri Lanka. SRL 11 is an alternative to the Sri Lanka's 28 footer widely in use presently.

A 28 footer (8.5m) in fiberglass, called the SRL 14, is now being constructed under this project to be introduced in mid this year.

A.D.B. fishery project's main objective, among others, is to increase the efficiency of the fishing vessels presently in use by retrofitting of sails and propeller nozzles on existing 28 foot boats.

Preliminary work on this project has begun and fishery experts are conducting experiments prior to formulating specific designs.

The East Coast Fishery Project is an on-going project financed by grant cum loan from the Netherlands. Included as part of its development activities is the introduction of 100 numbers 24'-30' (7.3-9.1) long boats of a new type specially designed for the east coast. Suitable design and types of sail-assisted boats are being evaluated presently.

Under Sri Lanka's Ministry of Fisheries Project, a committee was appointed and on its recommendation, the Ministry's consultant naval architect was requested to design a boat incorporating the following features:

LOW FUEL CONSUMPTION

USE OF SAIL

28 FT. OVERALL LENGTH (8.5M)

GOOD SEA BOAT

SUITABLE FOR GILL NETTING & LONG LINING

OVERNIGHT STAY OR 2 DAY ENDURANCE

INSULATED FISH HOLD

SPEED 7 KNOTS UNDER POWER.

The boat named D.S. 28 was designed and built in March 1983 to meet the above parameters. This boat in appearance is similar to the popular 3½ ton 28 footer common throughout Sri Lanka. The D.S. 28 is of G.R.P. construction.

Some of the important features of this vessel are listed below:

* Beam is wider at 9' (2.7m) compared to 8'6" (2.6m)

* The displacement and load carrying capacity is higher by 1 ton. The D.S. 28 is a 4½ tonner.

* Insulated fish hold in addition to a gear store.

* The D.S. 28 is powered by a 22HP engine compared to the 30-36 HP installed in the normal 28 footer giving a fuel savings of over 40%.

* A specially designed lugger rig is fitted. It is easy to handle and no stays are required which gives the boat a clear working deck. This traditional lugger rig is comprised of main and a mizzen sail.

* Deck is self draining with hatch on centre, and engine shelter is fitted aft over the engine. This arrangement is suitable for gill netting, long lining or pole and line.

* The boat has a well-flared bow and good bilge section to minimize rolling.

Preliminary trials have now been carried out. Under power the boat performs well and has, in fact, exceeded expectations. A speed in excess of 7 knots was achieved. The engine H.P. could be further reduced to about 18 H.P. Under sail the boat performed well. The sails were made locally. Use of sail and the engine showed that a very acceptable speed can be obtained aided by a reasonable breeze and with engine slow ahead. This is the prime objective of the design to use a combination of sail and power to achieve fuel savings.

The popular 3½ ton 28 footer with 30 H.P. engine consumes about 8-9 litres per hour at full speed. The D.S. 28 with 22 H.P engine consumes 4 litres per hour thus achieving a fuel savings of 40-50%.

Using a combination of sail and engine at ¼ full speed, a fuel savings of 75% can be affected.

CONCLUSION:

It is evident that in the future the sail-assisted fishing boat will play an important role in Sri Lanka's efforts to provide its people with protein rich diet. Resourses, both by way of expertise and funds, from foreign and local sources are being increasingly mobilized for studies in construction, techniques and economy. Prototypes have been built and trials are underway and commercial construction of these boats is no longer a distant dream.

ANNEX A

NUMBER OF TRADITIONAL CRAFT IN 1951 and 1952

YEAR	DUGOUT WITH OUTRIGGER		DUGOUT WITHOUT OUTRIGGER	LOG RAFT	PLANKED CRAFT	TOTAL
	SMALL	LARGE				
1951	3888	1704	1597	4745	1313	13247
1952	3492	1935	1926	2562	353	10268

(Authority: Administrative Reports of the Director of Fisheries, Sri Lanka)

ANNEX B

DUGOUT WITH OUTRIGGER	DUGOUT WITH-OUT OUTRIGGER	LOG RAFT	PLANKED CRAFT	TOTAL
A. NUMBER OF NON-MECHANIZED TRADITIONAL CRAFTS IN 1980				
4244	2289	4261	1465	12,259
B. NUMBER OF MECHANIZED TRADITIONAL CRAFT IN 1980				
327	552	2146	27	3,052

C. NUMBER OF MECHANIZED BOATS TIMBER AND G.R.P. IN 1980

TIMBER 28' 3½ TON BOATS	G.R.P. 28' 3½ TON BOATS	G.R.P. 17'-20' BOATS	OTHER BOATS OVER 32'	TOTAL
1791	1279	5738	38	8,846

Total No. of Craft in 1980 - 24,157

(Activity: The Ministry of Fisheries, Sri Lanka)

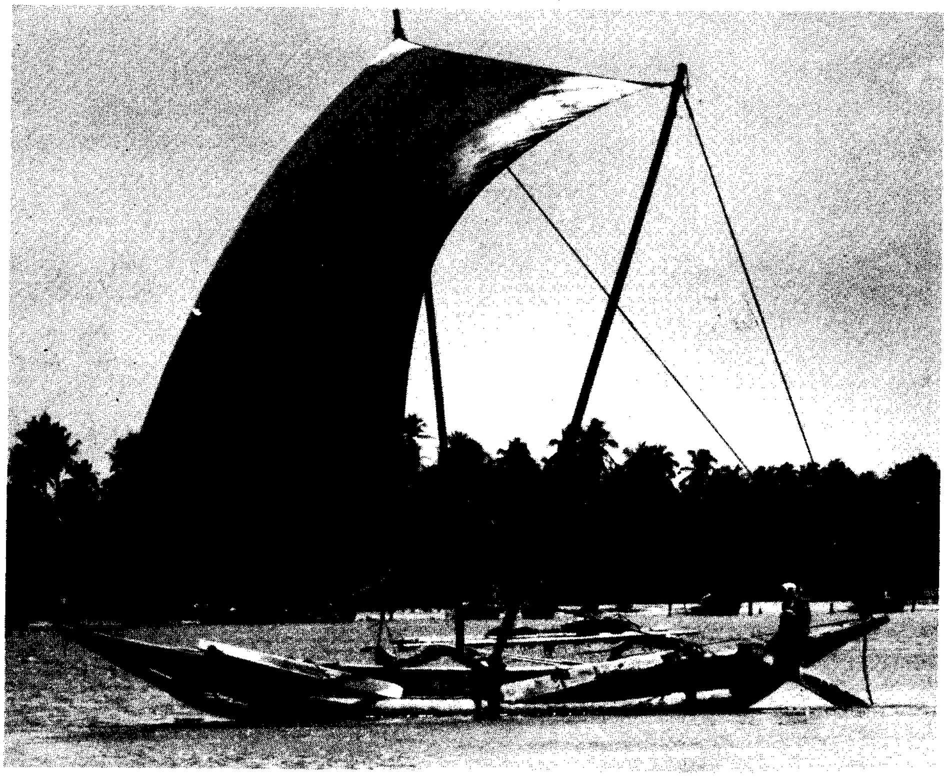
ISSUE OF 28' (8.5m) 3½ TON MECHANIZED BOATS

The total number of mechanized boats issued to fishermen, Fishery Cooperative Societies and special projects from the inception.

1958/59	-	84
59/60	-	300
60/61	-	251
61/62	-	362
62/63	-	154
63/64	-	92
64/65	-	213
65/66	-	85
66/67	-	113
67/68	-	92
68/69	-	200
69/70	-	159
70/71	-	162
71/72	-	219
1973	-	104
1974	-	37
1975	-	117
1976	-	251
1977	-	224
	TOTAL	3219

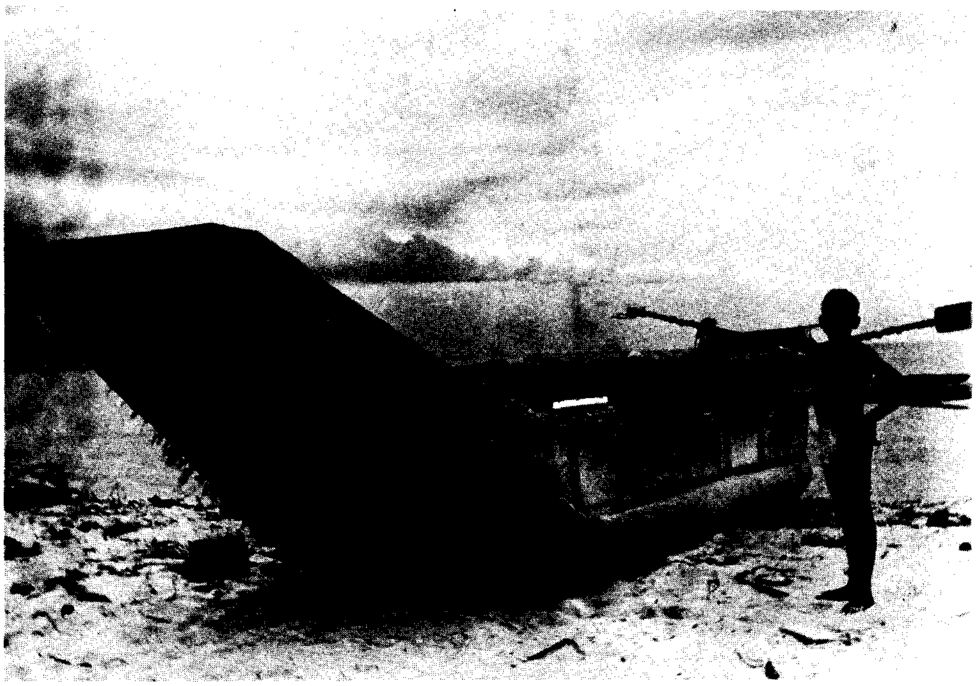
(Authority: Administrative Report of the Director - of Fisheries, Sri Lanka)

DUG OUT CANOE
Sri Lanka, traditional dugout canoe in operation in 1980.
Mechanized 2289; in operation in 1980, non-mechanized 552.

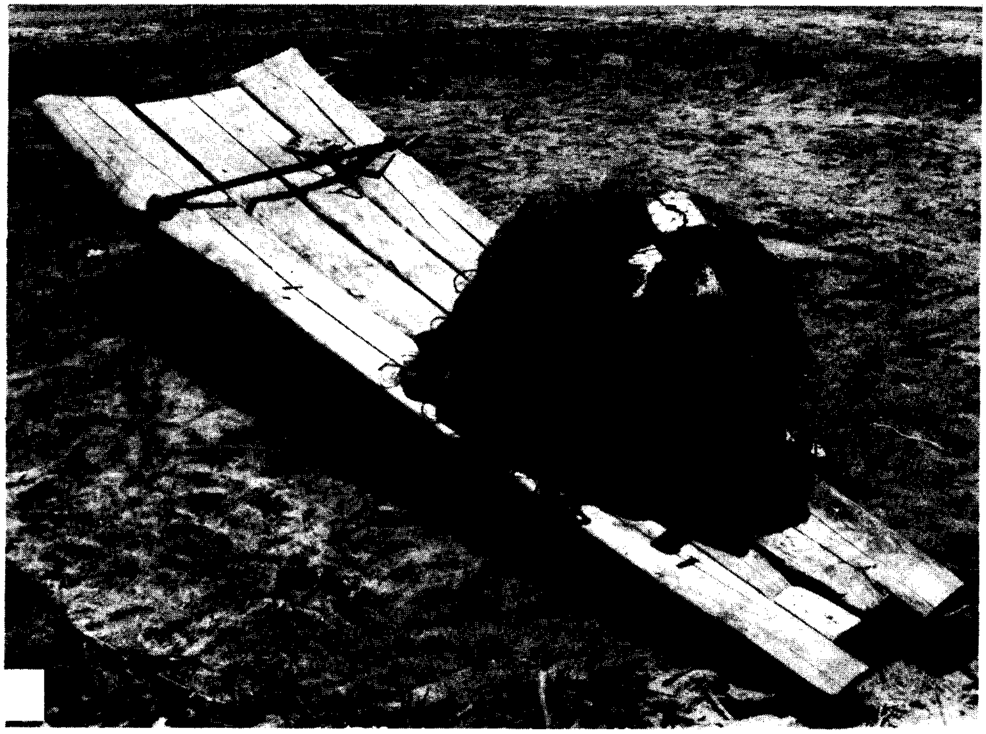


DUG OUT OUTRIGGER CANOE

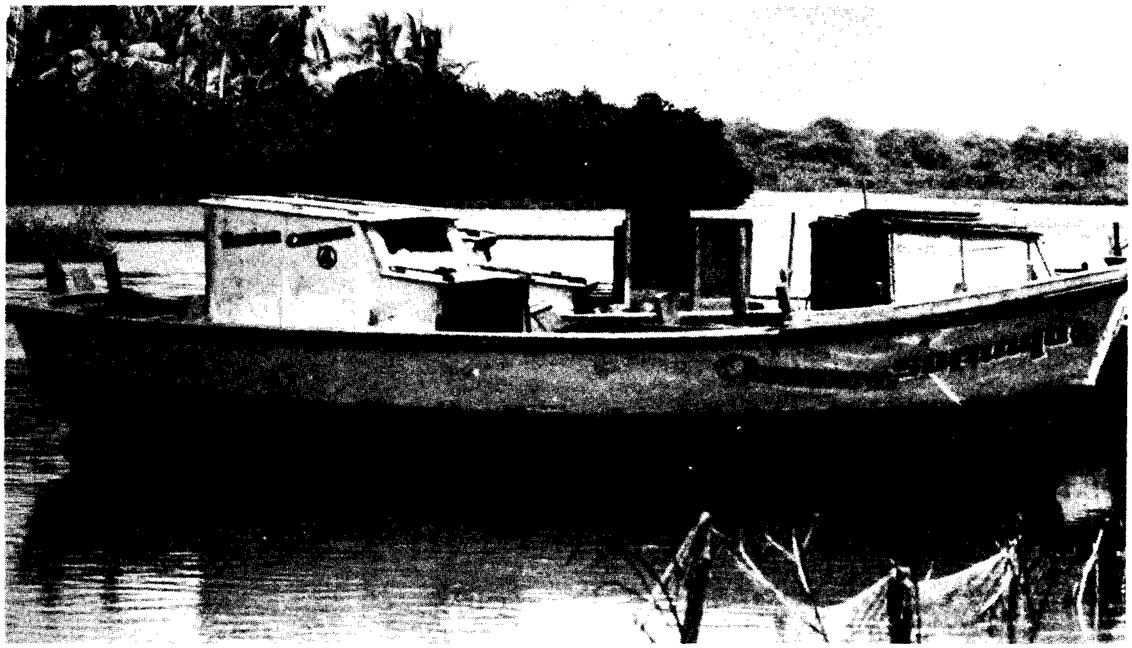
DUG OUT OUTRIGGER CANOE



PLANKED CRAFT



LOG RAFT - Sri Lanka log raft called Teppam or Kattumaram



Popular 3 1/2 ton 28 ft. mechanized fishing boat

D.S. 28 - Sail-assisted mechanized fishing boat introduced by the Sri Lanka Ministry of Fisheries in early 1983

SRL 11 - Sail-assisted mechanized boat introduced by the F.A.O. Bay of Bengal Project, Sri Lanka in 1981

PRESENTATION

PROJECT PESCA INDUSTRIAL A VELA

DEVELOPED FOR

ESTADO DO RIO GRANDE DO NORTE

BRASIL

INTERNATIONAL CONFERENCE ON SAIL ASSISTED COMMERCIAL FISHING VESSELS

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In the United States, I wish to thank, in particular, Bernie Arthur of Skookum Marine Construction Inc., who designed and will ultimately build the pioneer boats for the project; Ed Miller of Midwater Services Inc. who has advised of fishing methods to be used and is in the process of building these systems; Lee Links of Star-Kist Foods, Inc. who was one of the first to see the practicability of the use of sail to develop the offshore fisheries of northern Brasil.

The excellent research conducted by Dr. Phillip Connolly of SUDEPE which proves the practicability of the fishing methods to use, and also proves the existence of sufficient offshore stocks of tuna and related species to encourage development of this fishery, is the basis that this project was mounted upon.

ABSTRACT

Taking advantage of the travel opportunities offered in connection with my employment as tug-master under contract to Petrobras, the Brazilian national oil company, I became interested in 1979 in the potential of the un-exploited offshore fisheries in Brazil, especially tuna and related fin fish. During the course of my initial research, I have traveled to several of the main fish production centres, and have visited project bases of SUDEPE, PDP, PESCART and other agencies involved with fisheries development; shipyards, both large and mini; fishing ports; processing industries; universities where fisheries subjects are taught; and have sailed and operated all types of fishing vessels from small primitive "JANGADAS' to sophisticated tuna clippers. For over three years I have visited fishing villages in the praias, met and worked with the local fishermen, have studied their problems, and investigated their present fisheries.

The Project Pesca Industrial a Vela, which originated with my initial plan to build one sailing fish boat which I felt was ideal for operation in the offshore fisheries, developed when the state government took an interest in my project as a possible solution to develop their artisanal fisheries. The state's plans were obviously much larger, and the project has now developed into an integrated program which provides for new shipyard (boatyard) facilities, marine service and supply centre, renewal and modern-

ization of the entire fishing fleet of the state using sail as the major system of propulsion, and provides for support of the state operated fisherman's cooperative which has five bases located at strategic points along the coast of the state of Rio Grange do Norte.

Short Outline of Brazilian Fisheries

Brazil has a coastline of approximately 5,000 miles (8,000 km) long and an extensive river system. Some of its marine fishery resources are already fully if not over exploited but there are still additional unexploited and not yet fully exploited stocks in both inland rivers and lakes and in the Atlantic Ocean.

The total annual yield of the Brazilian fisheries is between 600,000 and 700,000 tons and the annual per capita consumption is less than 7 kg. Undoubtedly, this figure could be much higher would the supply be larger and better distributed. Brazilian fish exports consist mainly of high valued crustaceans and catfish, some tuna from the South, red snapper and grouper, while imports comprise frozen, salted and canned fish.

The fisheries in Brazil are extremely diverse owing to the diverse fishing conditions and to the great difference in the technological level of the fisheries infrastructure stemming from the pronounced regional differences in socio-economic development. In the South where the climate is more temperate and the continental shelf wide, there is a rather developed trawling industry supported by a very wide range of vessels starting with small 6 - 7 metre (20 - 23 ft.) long boats and going up to modern stern trawlers. In addition there is an industrial purse seine fishery for sardines. Some boats have converted to live-bait boats for tuna. In the central part of the coast between Rio de Janeiro and Sao Luis, the continental shelf narrows and is mostly untrawlable, rocky and coral bottom prevailing. Here the industrial fishery is supported mostly by handliners catching red snapper and other demersal fish and by primitive vessels fishing with lobster pots. In the North where the continental shelf again widens, trawling activities again prevail and the main objects of the fishery are shrimp and catfish.

Along the whole ocean coast of Brazil and in the many lagoons, lakes and rivers, literally hundreds of thousands of small-scale and artisanal fishermen are engaged in a partly commercial and partly subsistence activities using a wide range of fishing gear and methods, some of them rather advanced, e.g., trawling from motorized boats, but for the most part still traditional and quite primitive. Brazil has a considerable infrastructure which was associated with export-oriented fisheries and major production centres is quite modern and well-developed. It includes shipyards, processing plants, freezing and refrigeration installations, ice plants, fishing gear manufacturing and representation, market places, transport facilities, etc. There are still vast, especially rural and deep inland areas where lack of infrastructure and personal ambition and incentive presents one of the main reasons for the underdevelopment of fisheries.

As a result of my travels and research efforts and the suggestion offered by Lee Links of Star-Kist Foods, Inc. the central part of the coast, with a base at Natal, RN, was selected as a target area for the Project Pesca Industrial a Vela. The prevailing trade winds in this area were also a major consideration.

Star-Kist's, as well as the Brazilian government's interest was tuna. The tuna captured south of Cabo Frio, near Rio, was mainly Skipjack, which is fished using live-bait from larger specially equipped vessels. This is an industrial fleet, which leaves little room for a small operator (armador de pesca). The extremely high cost of diesel, the lack of wind or periods of light winds, and the lack of trained personnel were discouraging factors to a sail-oriented project in this area.

The fishermen of the central coastal area need no introduction to sail, as 90% of the existing fleet is already sail powered. Therefore the project objectives were to utilize this existing fleet, in conjunction with a fleet of newer, more modern boats coupled with transfer of technology of more sophisticated methods of fishing.

Climatic Conditions Affecting the Resource and Fishing Conditions

The climate of the central coast, referred to in Brazil as the Northeast, is hot and humid with the seasons offering little change except during the rainy season which starts in March or April. Winds are constant trades north of Cabo Frio, approximately force 3-4 year round. There are few storms.

There is a strong surface current condition which varies at different seasons which is influenced by the equatorial current arriving from Africa. This current arrives at about 3-4° S. latitude directly at the point of the Island of Fernando do Noronha, and splits with one current proceeding north along the coast towards the mouth of the Amazon River, and the other proceeding south toward Cabo Frio, where it encounters the cold current from the Malvinas. The circulating patterns associated with this current passing over the banks between Fernando do Noronha and the mainland (coast of Rio Grande do Norte) are associated with areas of upwelling which brings many nutrients and plankton to the upper layers and provides food chains for pelagic fish. Large pelagic species profiting from these food chains include not only the tunas which are highly migratory but also other species such as the mackerels, swordfish, dorado, and marlins for which there seems to be more than a modest fishery potential.

Potential annual catches of the larger demersal species which are presently not being exploited have been estimated by one source at around 20,000 tons, with an additional side catch of sharks and rays of around 15,000 tons. Small craft traveling relatively small distances using traps, longline, gillnets, or trolling methods would appear to have a considerable catching potential. For this reason the government is encouraging modernization and development of fleets of small craft to exploit the inshore coastal waters.

Before the introduction of the Project Pesca Industrial a Vela, little thought was given to the possible exploitation of the potential offered by the offshore banks, some 200-300 miles off the coast.

Fishing Gear and Methods

The gear presently being used consists mostly of simple handlines, with some trolling using only one or two lines by small sailing craft. The Project Pesca a Vela proposes using longlines; offshore gill nets, both surface drift and bottom set; and the trolling systems as developed by the albacore and salmon fisheries on the west coast of the U.S.A.

Locally Available Inshore Fishing Craft

There are three types of traditional fishing craft presently operating along the northeast coast of Brazil. Of these the first is the 'JANGADA' which is simply a platform or raft originally constructed with balsa logs, now as a small raft with an enclosed hull. These craft are from 3-5 metres (10-16 ft.) in length, constructed locally on the praias (beaches) by the fishermen themselves. These JANGADAS are usually manned by one or two fishermen, rowed or paddledand employ a small sail with a traditional curved mast. The second type of traditional craft is the small wooden sailing boat with a straight stem and transom stern also built locally with wood transported from the area of the Amazon. These craft vary in size from 6-9 metres (20-30 ft.), employing internal stone or concrete block ballast which is shifted manually each time the vessel tacks, manned by a crew of 3-5 fishermen, and propelled by a larger version of the traditional JANGADA sail with curved mast. For this reason they are also occasionally referred to as 'JANGADAS'.

These traditional JANGADA rigged craft operate almost exclusively under sail although some of the newer ones are also equipped with a small diesel engine. They form the greatest part of the Northeast fishing fleet and account for up to 50% of the fish landed in this region.

A recent development project by SUDEPE (PROSPECA/B.I.D.)utilizing resources from the Inter-American Development Bank resulted in several motorized vessels being built utilizing the same traditional sailing hulls but without the masts and sails. Operation of these craft has so far proven non-profitable because of the high cost of diesel, and the fact that they still continue to employ primitive fishing gear. Needless to say, many are considering mounting masts and sails to reduce their operating cost.

The third type of traditional craft is the typical lobster boat - LANGOSTEIRO, which are also constructed locally and are usually 12-14 metres (39-46 ft.) in length. These craft, normally crewed by 4-8 fishermen, are all motorized and at present none are sail or sail-assisted. The lobster fisherman in Brazil is in a class alone, as he knows little of actual fishing nor does he appear to care to learn. He also knows nothing about sail and isn't interested in cutting his costs as most boats are either company owned, or company subsidized.

Fisheries, Organizations and Infrastructure

SUDEPE - The Superintendencia para Desenvolvimento de Pesca is the Brazilian National Fisheries Agency. SUDEPE, with local offices at the major ports, is responsible for supervising and enforcing the country's fishing laws, control of the quality of the product landed, and for the overall development of the country's fisheries.

COLONIES DE PESCADORS - In the local villages there is generally a colony of pescadors (fishermen) which is supposed to represent the needs of the local fishermen and communicate these needs to SUDEPE. The original idea of the colony being able to supply the financial and equipment needs of the fishermen seems to have failed from lack of operating capital, and they seem to exist now only to assist SUDEPE in licensing and control of the fishermen.

COOPERATIVES - In Rio Grande do Norte, there was one cooperative in Baia Formosa which never really got off the ground as bad management and lack of support by the fishermen doomed it to an early failure.

A new cooperative, COOPERLIN, created under a program financed by the World Bank, PROJECT ESPECIAL DO CIADADES DO PORTE MEDIO, has constructed excellent refrigerated facilities at five major points along the state coast, seems to be a well organized effort supervised by the state. If they can resolve their initial lack of working capital problems, organize their management, and gain confidence of the fishermen, they should have a chance of success.

In most cases fishermen sell their catch to a buyer representing a major fish company, especially in the case of lobsters, or to a local fishmonger for a relatively low price.

In general, maintenance and repair facilities for boats, engines, and gear leaves much to be desired. These facilities are inadequate and a general shortage and high cost of spare parts renders maintenance work difficult. Most fishermen effect their own repairs and maintenance and dry the boat out on the beach at low tide.

Technical Advantages to be gained by the use of Sail Power

1. Technical constraints to economic operation of mechanized craft.

Studies of the boats operational in the various villages indicate that a large percentage of the motorized boats which are not being used in the lobster fishery are out of operation because of engine breakdowns, and to a lesser degree, hull defects and damage. Repair facilities and available spare parts, the low level of mechanical skills of the fishermen, and the lack of competent mechanics available to carry out servicing could be reasons for this poor operational percentage. The lobster companies with better organization seem to be able to keep their vessels operational.

The high cost of fuel, and declining inshore stocks seem to be the major reasons for the boats being put out of operation.

Serious balance of payment problems inhibit the importation of gear and equipment needed to help develop the offshore fisheries. In addition, few of the boats and engines are suited for rugged fishing conditions in open water.

2. The case for development of improved sail powered fishing vessels.

Given the problems of assuring mechanical reliability and taking into consideration the high cost of diesel oil (presently over U.S. $2.50 per gallon), it could be argued that a more appropriate solution should follow a course of action which is not so dependent on diesel engine power.

The dependable wind systems, steady trades year round, makes a good argument for the increased adaption of sail power. Either as a means of fuel savings in an engine powered craft or as a primary power source: sail permits the fisherman to continue or extend his operations. The introduction of rig modifications which will result in more efficient operations and increased ease of handling of adequate sail areas is justified.

Substituting a renewable energy source, wind (through the medium of a sailing rig) for non-renewable fossil fuels in the powering of fishing vessels is only justifiable in economic terms if the costs of investing capital in the proposed energy source can be compared to the monetary worth of the fossil fuel saved.

In addition, consideration should be given to increased operational efficiency when lost operational time due to mechanical breakdown can be recovered by the use of sail power.

PROJECT PESCA INDUSTRIAL A VELA

The state government of Rio Grande do Norte, Brazil, through the Compania de Desenvolvimento Industrial do Rio Grande do Norte-CDI/RN, contracted the company CACDORES DO MAR (Capt. Donald Richard Reid) to study the state's artisanal fisheries and to offer a solution to develop the offshore fisheries in the banks and islands bordering the coast of this state, utilizing, if possible, sail power to minize operational costs.

As a result of these studies, a project 'PROJECTO PESCA INDUSTRIAL A VELA' was presented to SUDEPE for approval. This project, which has now been officially approved by SUDEPE, includes a complete program starting with modification of the present methods of construction in Brazil of modern fiberglass sailing trollers as used on the west coast of the U.S.A. in a 'joint-venture' shipyard to be constructed in Natal; importation of an initial fleet of five to six modern fiberglass sailing fishboats resulting in a transfer of technology agreement with Skookum Marine Construction, Inc.; construction of a new type of 10 metre (32.8ft) catamaran designed by John Marples and introduction of a larger monohull sailing troller designed by Edwin Monk along the lines of the famous Skookum boats; transfer of fishing technology by Ed Miller of Midwater Services, Inc. and Redden Net; and importation of specialized equipment for equipping converted boats.

Fishing methods to be utilized include trolling with a system that combines California albacore methods with methods developed in the Northwest of the U.S.A. for slamon. Passive systems include large ocean drift/gill nets and longlines.

Targeted fisheries are tuna and related fin fish, swordfish and marlins, and sharks. Squid, which are in abundance, will be used as bait and will also be exported. The offshore banks are extremely rich in fish resources, which the present vessels are unable to exploit with existing methods.

A training program, in conjunction with the state universities and the Brazilian Minister of Portes and Coast (Marinha), has been planned which will prepare local fishermen to navigate offshore and to handle the new fishing systems. Included in this course will be a short course on cooperative marketing to enable the fisherman to better understand the advantages and benefits to be gained by supporting the state cooperative.

A special training course stateside will be for certain technicians, masters, and engineers who will work with the program.

Coordination of operations and implantation of the project will be the direct responsibility of the new foundation - CMAT - Fundacao para Desenvolvimento de Pesca em Pequena Escalam which has been created to create a line of financing and transfer of technology.

Economic Analysis of Project

A copy of projected fish stocks and capture rates from the project is included in the copy of the project which accompanies this report. In addition, is a copy of an economic analysis by A. Nelson Swartz, Ph.D., marine economist. This analysis justifies the investment by fishermen associated with the project in the sailing troller proposed by Bernie Arthur of Skookum Marine Construction, Port Townsend, Washington. This analysis projected return based on 20 trips per year (a rather conservative amount of voyages) and for a return based on 30 trips per year, this is a figure that fisheries personnel who are familiar with the area, feel is more probable.

The following information that reflects the prevailing conditions in the Brazilian economy was fed into the computer as a basis of this analysis. Results are in Cruzieros, the Brazilian currency.

Economic Factors:

Brazilian Inflation	106%
Fuel Inflation (Brazil)	138%
Seafood Inflation (national)	96%
Seafood Export Influence	95%

Exchange Rate (day of analysis) = CR $227 = U.S. $1.00

Poupanca rate (if same investment was applied to long term bank deposits or savings accounts) (replacement value of money) 84%

Price of vessel = U.S. $553,469 or CR $125,637,372

Operational Factors:

Distance Traveled	400 miles	644 KM
Trip Duration	Adv. 9 days	180 days per year
Number of trips	20 (30)	115848 KM/YR
Avg. Cruise Speed	9 knots	17 KM/HR
Fuel Consumption	0.18 L/HP/HR	22 L/HR
Horsepower	120	39 HR/TRIP
Sailpower % Used	50%	6950 HR/YR
Fuel Used		75065 L/YR

Revenues:

Tuna & Finfish	4,091 K/TRIP
Locally sold	20%
Exported	80%
Local price	CR $220.00 /K
Export price	CR $207.33 /K
Swordfish/Shark	5,480 K/TRIP
Average price	CR $281.60 /K

Comparable reports are being prepared by Dr. A. Nelson Swartz on the following:

1. Comparing the project vessel with a similar motorized vessel under the same conditions - no sail power.
2. Lobster boat traditional converted to sail-asist and for tuna.
3. Artisanal sailing craft.

Government Incentives

This project has the complete support and approval of both State and Federal government in Brazil, and investors, both Brazilians and foreigners interested in investing in the Brazilian fisheries sectorare invited to contact CMAT. There are many tax breaks and incentives to be obtained, and foreign investment is treated equally as if it were national, in fact possibly with more priorities.

These incentives include:

FUNDACAO CMAT - Funds donated to CMAT may be channeled through participating U.S. Foundations. Information on these foundations will be provided to interested persons upon request.

DIRECT INVESTMENTS - Funds placed with the Foundation CMAT for direct investment in particular companies or in particular areas of the fishing industry receive the following incentives:

- Reduced or no income tax for 10-15 years;

- Reduced or no import duties on vessels and equipment required for fisheries projects;

- 30% reduction on fuel costs if over 10% of the product of a particular project is to be exported;

- Government participation in the capital structure of this particular Brazilian company from resources of SUDEPE/FISET - the Brazilian government will enter 3 to 1, i.e. three times the investment with capital participation.

- Long term, low interest loans for construction of new vessels or purchase of specialized equipment;

- Special incentives for the development of new fisheries reserves, and for the use of alternate energy;

- Additional incentives for investment in the area of SUDENE, the Northeast of Brazil which is one of the lowest income areas in the country.

The Project Pesca Industrial A Vela alone, when fully operational will affect the income producing abilities of over 25,000 fishermen. Other projects in the areas of fisheries development include:

Fishing Terminal

Shipyards

Marine Supply Dealers

Marine Equipment Manufacturing

Commercialization of Specific Fisheries Product, i.e. in planning stages for commercialization of shark, and cannery.

Boat Operation Companies

Aquaculture - Shrimp and Fish Production

Algas - Commercialization of

Net and Line Factory

Fiberglass Boat Manufacturing

Sail Loft

Marine Electronics Sales & Service

Refrigeration Sales & Service

SAIL-ASSIST ALTERNATIVES FOR AUXILIARY PROPULSION

Lloyd Bergeson
Wind Ship Development Corporation
Norwell, Massachusetts 02061

INTRODUCTION

"Sail-assist" is a term coined by Wind Ship to describe the portion of the wind propulsion spectrum (Figure 1) in which most of the ship's propulsive power is generated by the engine driving a screw propeller, and sail power is used as an auxiliary, to save fuel or increase speed. The economics of operating in various regions of the spectrum were investigated by Wind Ship in a 1981 report prepared for the U.S. Maritime Administration (MARAD), (Reference 1). The main findings of this report were:

- A properly engineered automated sailing rig requires no additional manning and is an economically advantageous propulsion system when used in conjunction with conventional screw propulsion.

- Of the hardware alternatives examined in the study, wing sail rigs offer the greatest potential for simplicity, reliability and cost effective performance.

- Sail-assist ships, with only fractionally smaller power plants than conventional vessels, will not experience the operational difficulties in maneuverability and reliability associated with pure sailing vessels.

- Sail-assist offers fuel savings of 20% to 30%.

- A properly designed sail-assist ship can be built for approximately the same cost as an equivalent conventional motor ship.

- Existing motor ships can be retrofitted with sail because sail-assist is effective on conventional hull forms.

These conclusions encouraged Wind Ship to continue research and development in the field of sail-assist. Under contract to Ceres Hellenic Shipping Enterprises, Wind Ship designed two 3000 square foot rigs to provide direct comparative results between the unstayed cat rig and the wing sail. The cat rig was installed aboard the M/V MINI LACE, a 3100 dwt general cargo ship, and the first year's fuel savings of 24% have exceeded the predicted savings of 20%. Development of the wing sail has also proceeded with the construction of a 1/3 linear scale model of the 3000 square foot design and preliminary results are encouraging.

The primary areas of application for Sail Power Units (SPUs) at present are new buildings and existing vessels with service speeds of up to 18 knots and up to 40,000 dwt in size. Liquid bulk carriers are the simplest ships to apply sail-assist to, and container ships the most difficult, but compatibility with shipboard or shoreside cargo handling gear is achievable on almost any ship. Some specific applications are addressed at the end of the paper.

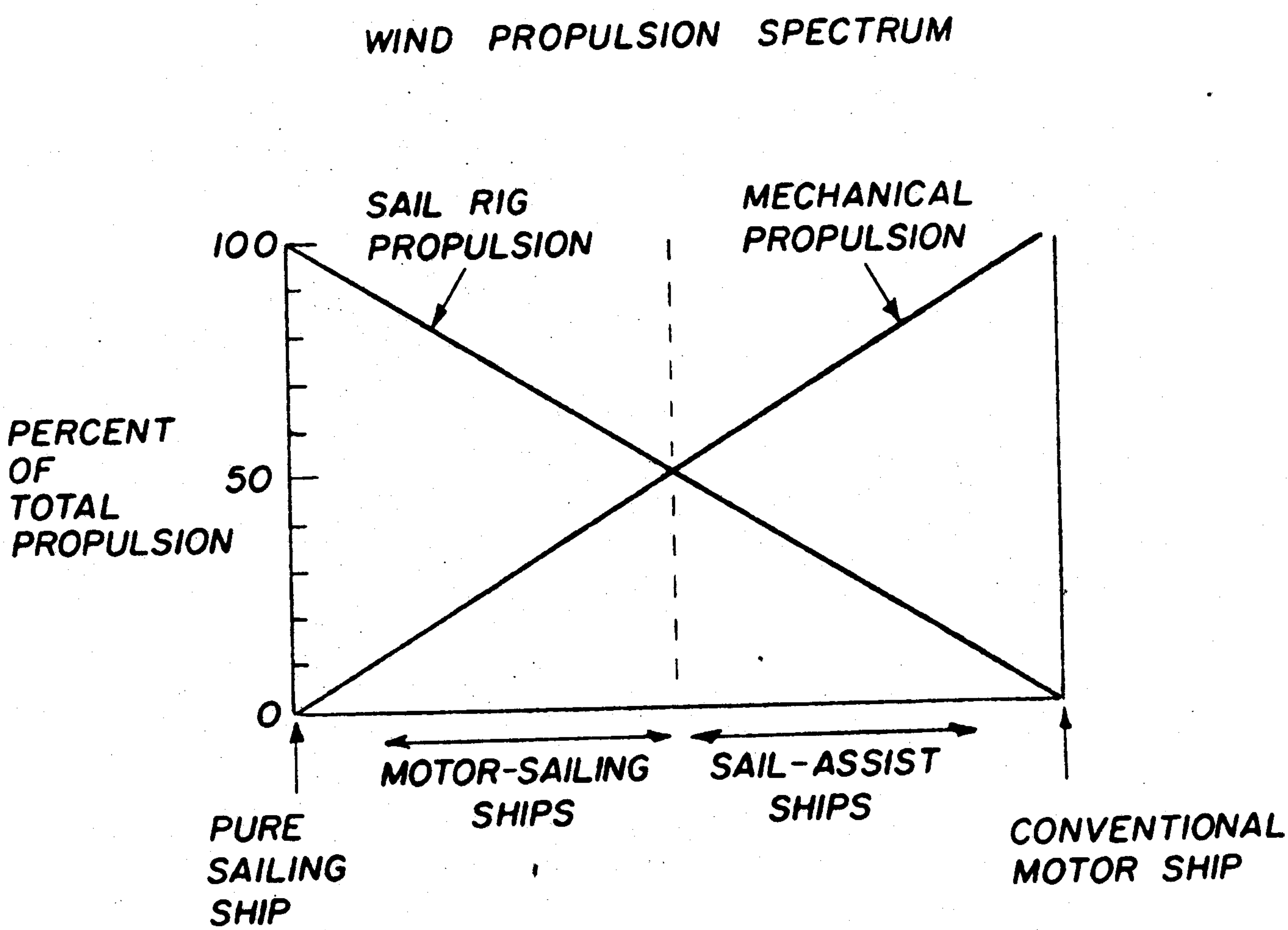

WIND PROPULSION SPECTRUM
SAIL RIG PROPULSION
MECHANICAL PROPULSION
100
50
0
PERCENT OF TOTAL PROPULSION
MOTOR-SAILING SHIPS
SAIL-ASSIST SHIPS
PURE SAILING SHIP
CONVENTIONAL MOTOR SHIP

FIGURE 1

ANALYSIS OF RIG ALTERNATIVES

Numerous devices have been proposed for wind propulsion of ships. For the MARAD report, eight wind propulsion systems which represent the range of proposed modern rig alternatives were evaluated in terms of technical and economic potential for merchant ship propulsion. The eight rig alternatives are depicted in Figure 2.

A sailing rig is a wind propulsion system that may be considered in terms of the same economic parameters used in evaluating conventional propulsion machinery:

- propulsive performance
- initial cost
- operating cost
- weight
- size (volume or area occupied by the system)
- reliability
- safety

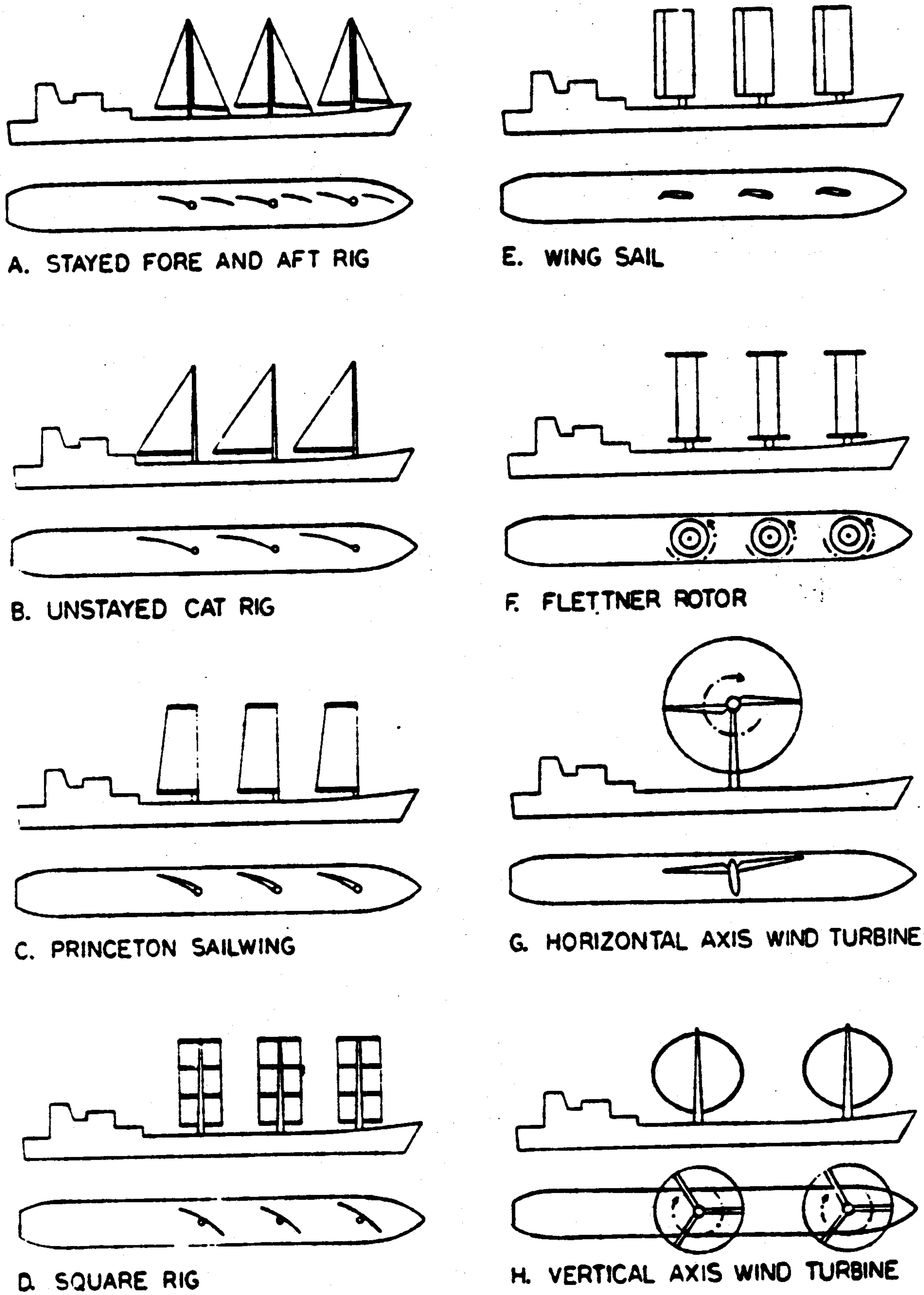
In addition to these factors, the presence of the propulsion system may impact other aspects of ship operation. For sailing rigs, the primary impact is on cargo handling with secondary impact on visibility.

A basic concept design was developed for each rig type and propulsion performance predicted. Design criteria were specified for the selected rigs - mast height, sail area, and maximum full sail wind speed were the main criteria. Other criteria covered operational considerations and storm survival. Analysis of structural loads yielded equipment specifications and the dependence of rig weight and cost on the major design criteria. The weight and cost estimating formulas were employed in a parametric study to determine the overall relative merit of the rig alternatives.

Based on these design studies, the rig alternatives were rated in terms of relative potential for shipboard application in the near term. The rankings are summarized in Table I.

Stayed masts were found to weigh nearly as much as unstayed masts, and their inferior aerodynamic performance, and interference with cargo handling operations caused the stayed fore-and-aft rig to rate below the unstayed rigs. Square sails, despite their ability to fill up the envelope available for sail, were found to have relatively higher cost for their aerodynamic performance due to the complexity of the rig.

The unstayed cat rig and the wing sail were found to have the greatest potential for immediate application to marine propulsion. Both rigs are simple and reliable, have excellent propulsive performance, and are compatible with vessel operations. The findings of the MARAD report encouraged Wind Ship to continue the development of these two rigs and led to the design, construction, and installation of a 3000 square foot cat rig that entered commercial service in September of 1981 aboard the m/v MINI LACE. (Figure 3)



RIG ALTERNATIVES

Figure 2

TABLE I

RELATIVE MERIT RATING FOR RIG ALTERNATIVES

RIG	PROPULSIVE PERFORMANCE	INITIAL COST	OPERATING COST	WEIGHT	SIZE	RELIABILITY	INTERFERENCE WITH CARGO	OVERALL RANK
UNSTAYED CAT RIG	BEST	LOW	LOW	MEDIUM	LARGE	GOOD	MINIMAL	1
WING SAIL	BEST	LOW	LOW	LOW	MEDIUM	GOOD	MANAGEABLE	2
SQUARE SAIL	GOOD	HIGH	MEDIUM	HIGH	MEDIUM	POOR	MINIMAL	3
STAYED FORE-AND-AFT RIG	GOOD	LOWEST	LOW	MEDIUM	LARGE	MEDIUM	MAJOR	4
PRINCETON SAIL WING	GOOD	HIGH	LOW	LOW	MEDIUM	GOOD	MINIMAL	5
FLETTNER ROTOR	UNCLEAR	LOW	HIGH	LOW	SMALL	?	MINIMAL	6
WIND TURBINES (HORIZONTAL OR VERTICAL AXIS)	POOR	VERY HIGH	VERY HIGH	HIGH	VERY LARGE	NONE	MINIMAL (HA) MAJOR (VA)	7

CAT RIG SAIL POWER UNITS

CAT RIG MK I - THE MINI LACE SPU

Shipowner's Requirements & Design Criteria

The basic requirements for the MINI LACE sailing rig or Sail Power Unit (SPU) as stipulated by Mr. George Livanos on behalf of the owners, Ceres Hellenic Shipping Enterprises, Ltd., were as follows:

- Economic viability (substantial fuel savings)
- Simplicity
- Rugged reliability in continuous service at sea
- Remotely operable from the bridge
- No additional crew required
- Design and installation subject to approval of the American Bureau of Shipping (ABS)
- No interference with cargo handling

In response to these requirements, Wind Ship determined design wind speeds for the structural and construction design and the rig. The rig was designed to be fully operational (with full sail) in winds up to 35 knots, and to survive winds of 150 knots when furled.

Principal Dimensions

Mast height of the rig was specifically limited by the height of the Sunshine Bridge 160 miles above the mouth of the Mississippi River. The boom length was constrained by clearance to a cargo crane at midships. These effectively determined the maximum sail area that could be fitted. The dimensions are:

Sail:	
Area	2940 sq ft
Luff length	105 ft
Foot length	57 ft
Mast height above ballast waterline	134 ft
Boom length	60 ft

Mechanical Features

The system provides hydraulically powered control of the amount of exposed sail, the angle of the sail in relation to the vessel, and clew outhaul and downhaul tension. These functions are all controlled electrically from the bridge, so that no manual handling of the rigging is required.

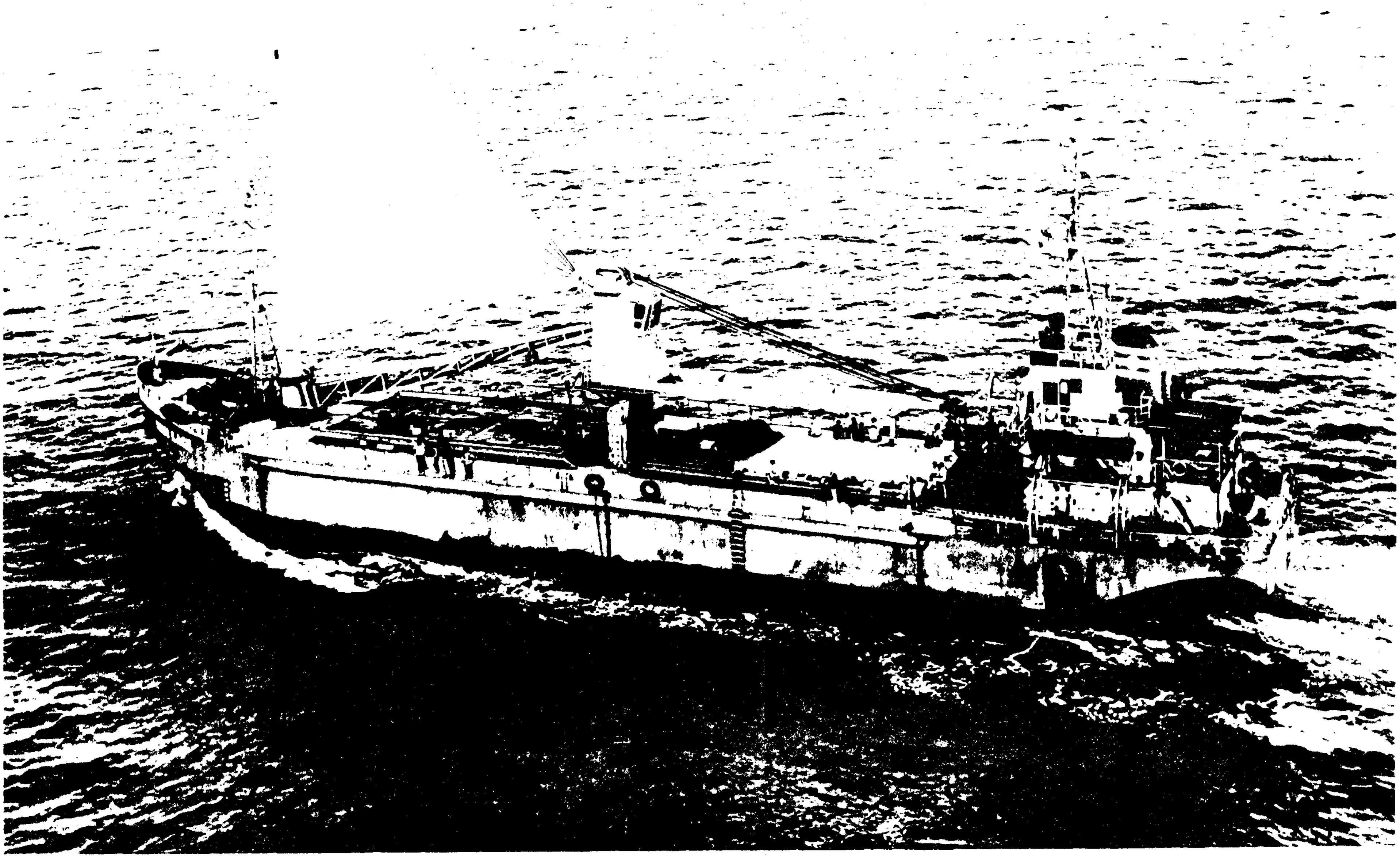


Figure 3

MINI LACE on Sea Trials at Buzzards Bay

The SPU is comprised of three major structural components. The first one is the rotating frame which acts as the structural backbone of the rig. Both the boom and the mast are attached to this structure. The second structure is the unstayed mast which stands 116 feet above the deck and is mounted via a slewing ring type bearing to the top of the rotating frame. The third structure is the boom which is cantilevered off the rotating frame. The boom and the frame rotate as a unit on a second slewing ring type bearing mounted between the bottom of the rotating frame and the rig foundations.

Hydraulic sheet winches, mounted on the boom, control sheet lines to swing the boom out to the desired angular position. The mast and boom rotate independently. A hydraulic motor rotates the mast in relation to the boom so that the sail may be reefed without changing the position of the boom.

The 3000 square foot loose-footed triangular sail sets on slides from a track on the mast. Tension on the clew of the sail is provided by an outhaul and a down-haul, which operate independently of each other. The outhaul line, under continuous tension in conjunction with the rotation of the mast, acts to take in or let out sail. The downhaul mechanism is mounted on the boom and connected to the clew, and travels in and out along the boom with movement of the clew, maintaining a continuous downhaul tension during such movement. Adjustment of tension on the outhaul and downhaul is provided by hydraulic winches and cylinders.

Performance Record

An engineering study was undertaken using Wind Ship's computer-aided Retrofit Analysis Model to predict annual fuel savings for the MINI LACE. The power generated by the rig is a function of the wind conditions in which the ship operates, and estimates of "rig horsepower" were made. Rig horsepower is the net reduction in required engine output achieved with the sailing rig in a specified wind condition while maintaining a constant service speed. If, instead of throttling back, the "standard" engine revolutions are maintained, the rig horsepower increases the total propulsive thrust and increases the ship speed accordingly. Figure 4 is a plot of the MINI LACE's rig horsepower vs. true wind for a full range of wind speeds. By averaging the fuel savings over the wind conditions expected on the given trade routes, fuel savings predictions of 20% annually were made.

The SPU has now been in service for 18 months. The owner's basic requirements have been fully met, and performance expectations have been exceeded. The average daily fuel rate has been cut by 24% and the average speed has been boosted 5%, largely without throttling back. On one favorable sailing route - New Orleans to Jamaica - the fuel savings come to 36% with an 18% speed increase.

In addition to these performance records, there have been other unexpected benefits. Use of the sail in heavy, confused seas allowed the m/v MINI LACE to maintain her 7 knot service speed when sisterships were slowed to 3 knots. When the engines were experimentally throttled back to compensate for sail generated thrust, fuel savings of over 30% were recorded, and certain ballast runs gave reductions of 60% to 80%. Mississippi River transit time from the sea buoy to New Orleans has been cut in half. Also, the use of the sail has enhanced ship operation in the heavy currents and is generally called for by the pilots. In one case, the MINI LACE sailing rig brought the ship into port on schedule after an engine failure had occurred at sea.

Some of these positive results are not easily quantified and run counter to intuition. For example:

- the ability of any ship with a sail on it to meet the improve schedule
- the ability to use sail-assist in heavy river currents and close quarters

As these benefits become more widely appreciated, the knowledge will contribute to the acceptance by shipowners of the fact that sail power units are "mature", reliable propulsion devices that can be specified on both new construction and retrofits with confidence.

Economics

The rig cost, exclusive of engineering, was $250,000. Based on the owner's records for fuel consumption, the average annual savings is $48,000 for the current fuel price of $327 per metric ton. The increased revenue from speed increase and the consequent extra voyages is $9,200 per year for a time charter rate of $2,000 per day. The total yearly benefit is $57,200. When the investment period is based simply on rig cost the first year's fuel savings, the rig cost is returned in 4.4 years. However, if the same criterion is applied to a year of operation on favorable sailing routes, the total economic benefit goes up to $148,000 and the payback period goes down to 1.7 years. An economic summary is presented in Table II. No figure for maintenance is included as the nominal maintenance required was performed at sea, except for repair to the sail. The annual sail maintenance was included in the price of the sail based on a five-year service life.

CAT RIG MK II - DESIGN REFINEMENTS

This rig is functionally the same as the CAT RIG MK I SPU. The principal changes are to unitize and rationalize the design for production and to make preassembled and pretested sail power units more easily installed or retrofitted on a large variety of ships in the shortest possible ship availabilities. (48 to 72 hours is an attainable goal for a rig installation availability). The MK II rig also offers the option of substituting a unique combination of hydraulic cylinders to move the boom positively through a 170^{o} rotation as opposed to the MK I system of boom control by means of wire rope sheets. A general arrangement for a Cat Rig MK II is shown in Figure 5. As in the case of the MK I rig, a hand-operated emergency furling system is provided in the event of power failure. Both the Cat Rig MK I and the Cat Rig MK II are proprietary hardware with U.S. and foreign patents applied for.

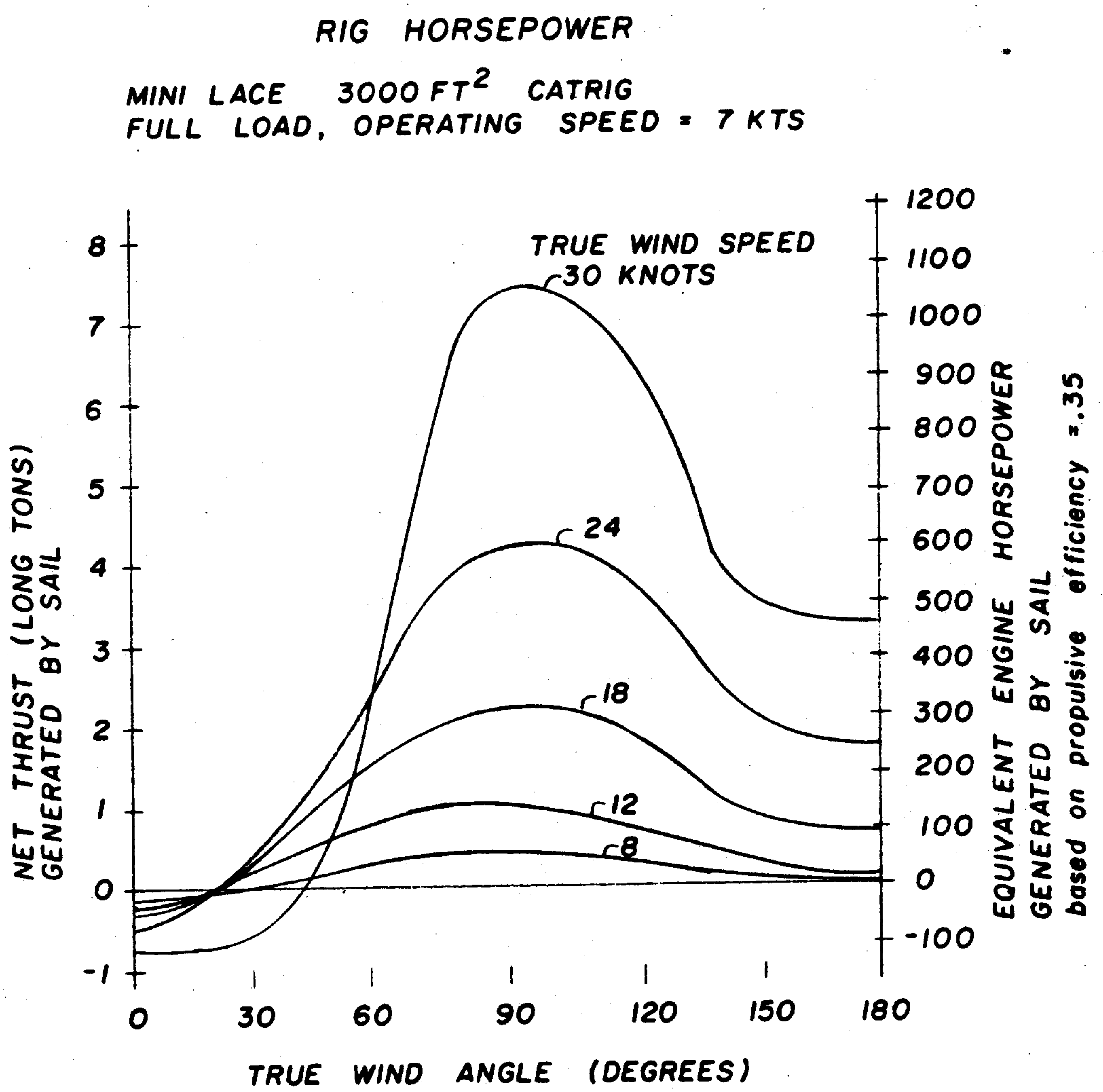

RIG HORSEPOWER
MINI LACE 3000 FT2 CATRIG
FULL LOAD, OPERATING SPEED = 7 KTS
TRUE WIND SPEED
30 KNOTS
24
18
12
8
NET THRUST (LONG TONS)
GENERATED BY SAIL
EQUIVALENT ENGINE HORSEPOWER
GENERATED BY SAIL
based on propulsive efficiency = .35
8
7
6
5
4
3
2
1
0
-1
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
0
30
60
90
120
150
180
TRUE WIND ANGLE (DEGREES)

FIGURE 4

TABLE II

MINI LACE SAIL-ASSIST PERFORMANCE RECORD

I. OWNERS REPORT-AFTER 14 MONTHS SERVICE
(Comparison of MINI LACE with sisterships without auxiliary sailing rigs but with similar propulsion plants)

FUEL SAVINGS & SPEED INCREASE
(Minimal throttling back of engines)

Route Scenario	Ship(s)	Actual Average Fuel Rate (tons/day)	Actual Average Speed (knots)
TRAMPING	MINI LACE (w/rig)	2.13	5.70
	MINI LARK & MINI LADY (no rig)	2.79	5.45
	Differences:		
	Av. Fuel Savings	.66 t/d (24%)	
	Av. Speed Increase		.25 k (4.6%)
MOST FAVORABLE ROUTE(S) FOR SAILING	MINI LACE (w/rig)	1.78	6.42
	Differences:		
	Av. Fuel Savings	1.01 t/d (36%)	
	Av. Speed Increase		.97 k (17.8%)

II. ECONOMIC CONCLUSIONS BASED ON OWNER'S 14 MONTH DATA
(Based on Fuel @ $327/Metric Tons)

Tramping Mode

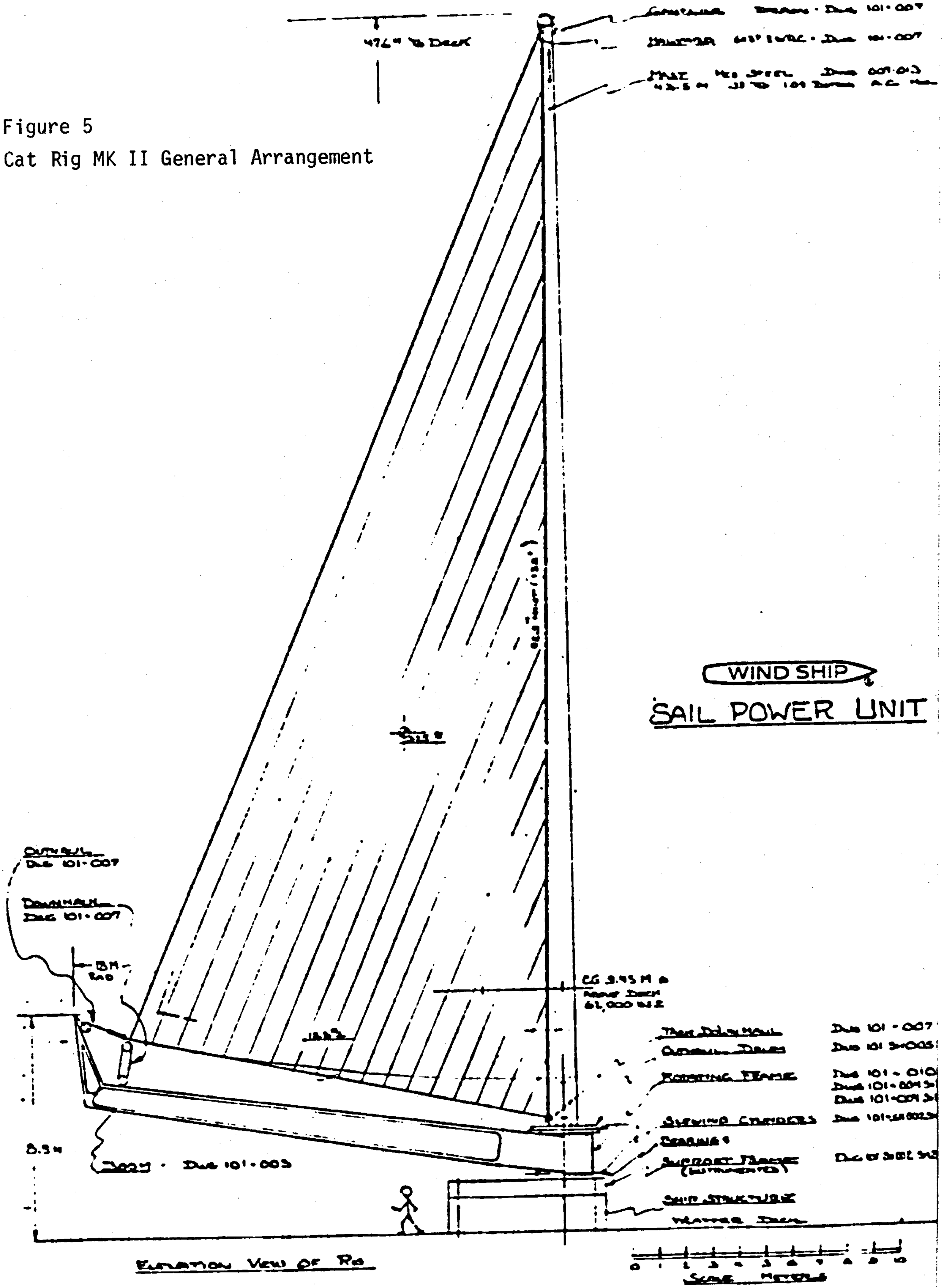
Annualized fuel savings	$48,000
Increased revenues/extra voyages	9,200
Total yearly benefit	$57,200

Full Time Operation on Most Favorable Sailing Routes

Annualized fuel savings	$ 70,000
Increased revenues thru extra voyages	78,000
Total yearly benefit	$148,000

Mini Lace Prototype Rig Cost (1981)	$250,000
Range of Rig Payback Depending on Route Scenario (Simple payback w/o cost of money)	1.7 - 4.36 years

Figure 5
Cat Rig MK II General Arrangement



WING SAIL POWER UNITS

Wind Ship Wing Sail

The wing sail was the second alternative identified by the MARAD report as possessing potential for utilization in auxiliary ship propulsion. A conceptual design was carried out as part of the MARAD report. A schematic arrangement is shown in Figure 6. The sail was a symmetrical NACA 0015 airfoil section with a 20% plain flap. The wing structure was framed of steel with plywood sheathing. The entire wing bore on a mast step radial/thrust roller bearing. This design was developed in more detail for a project to provide a direct comparison with the cat rig by putting a 3000 square foot wing sail on a sistership of the MINI LACE. Detailed design showed the wing to weigh more than anticipated. In addition, aeroelastic studies predicted that the wing as designed might experience dangerous bending-torsion flutter when operating in 50 knot wind. Therefore, four major design changes were made:

- the airfoil thickness was increased to NACA 0018
- the pivot point was moved forward from 15% to 10% of the chord
- the steel framing was changed to wood
- the main bearing was moved to the top of a stubmast one-third of the way up the wing

Another detailed design was carried out invoking features that were not in the MARAD conceptual design, and significant improvements were made in weight, cost, and aerodynamic stability. The design's several unique features have been the subject of U.S. and foreign patent applications.

Scale Model Wing Sail

In order to conclusively prove the radical aspects of the design, Wind Ship built a one-third linear scale model in September, 1982. The test rig is thus of sufficient size to avoid scaling up uncertainties and errors when forecasting aerodynamic performance for full scale wing sails. The scale model is virtually an exact replica of the 3000 square foot design: bearings, the framing system, the rotating drive system were all the same. The operational characteristics of the wing sail have now been completely proven:

- The concept of passive feathering has been verified. With the brakes released, the wing weathervanes safely in gusts of up to 60 knots.
- The drive system controls the wing easily and effectively.

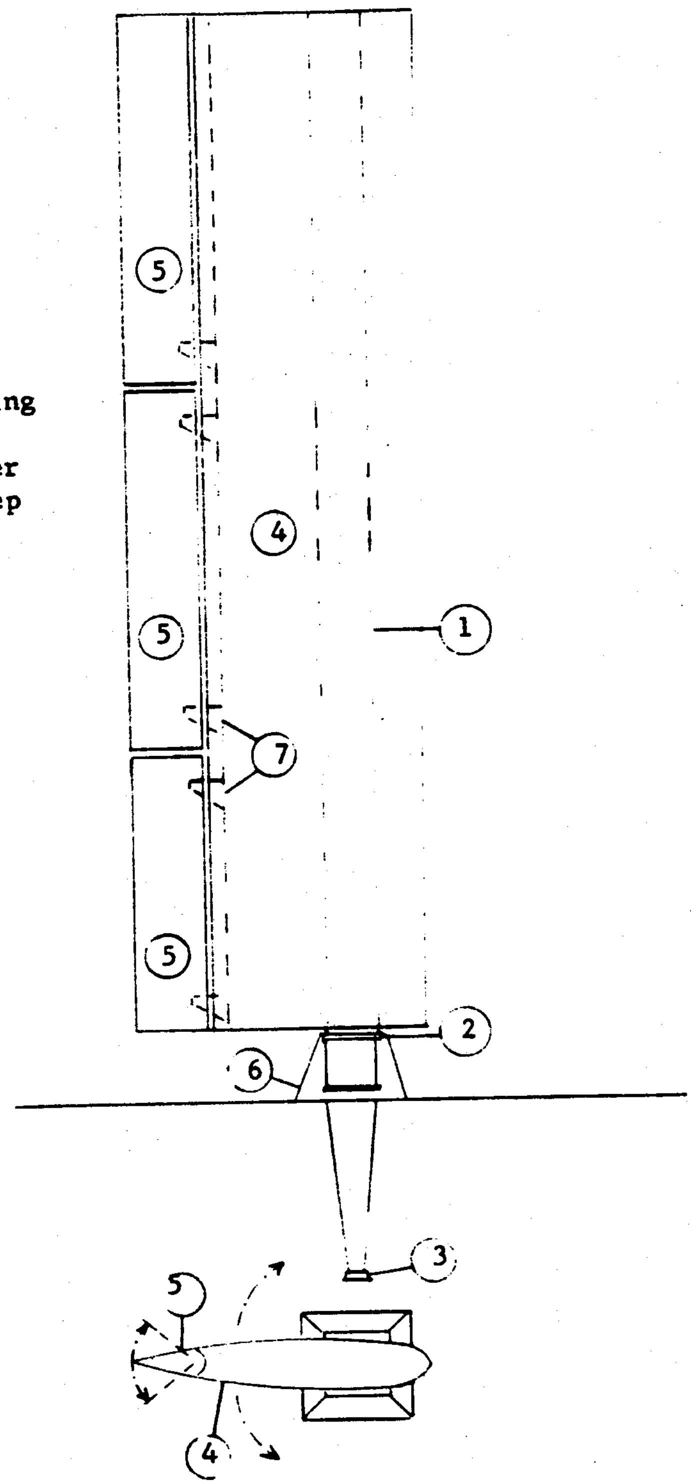
Figure 7 shows the wing sail feathering passively in high winds. Preliminary test results show that the wing sail's propulsive performance is indeed excellent - a maximum lift coefficient of 2.0 has been indicated by measurements taken from the instrumented test stand. Wind Ship plans to verify the initial test results by conducting fully instrumented tests under controlled conditions, hopefully in a large wind tunnel.

Figure 6

Wing Sail
Concept Design for MARAD Report (1981)

<u>Key Items</u>

1. Rotating Mast
2. Radial Roller Bearing (Mast)
3. Radial/Thrust Roller Bearing at Mast Step
4. Wing
5. Flap Segments
6. Turning Gear with Feathering Release
7. Flap Actuators



WING SAIL POWER UNITS (Cont.)

The propulsion performance improvement of the wing sail over the cat rig is demonstrated by comparing the fuel use plots of Figure 8. The comparison is for MINI-class ships with 3000 square foot SPUs fitted.

Other Wing Sail Research

Wind Ship is by no means alone in developing wing sails for ship propulsion. The Japanese, French, and English are all doing basic research in support of engineering efforts to fit symmetrical airfoil wing sails on motor ships. Nippon Kokan K.K. recently reported having performed wind tunnel tests (at small scale) on an NACA 0018 section with 35% plain flap and aspect ratio of 3.0 (Reference 2). The results show a substantial improvement in propulsive performance over the NKK-type square sail. At the same time, the French unveiled 1/50 scale model tests on a 14.5 knot 3100 dwt chemical product carrier (Reference 3). The wings had special profiles, had a 16% thickness ratio, and had double flaps. The aim of the study was to achieve more than 15% fuel savings.

Walker Wing Sail has presented the most sophisticated and well publicized wing sail effort. Their triplain wing, trimmed mechanically by a small flap through a linkage, bears a remarkable resemblance to Anton Flettner's metal triplane sail (Reference 4). The Walker wing sail appears to have great potential, but auditable aerodynamic and vibrations data for the sail are not yet forthcoming.

SAIL-ASSIST APPLICATIONS

The favorable economics of sail-assist extend to ships with service speeds of up to 16 knots or so. A sample case is presented for a typical 15,000 dwt general cargo ship in Figure 9. This shows the relative fuel consumption of a sail-assist ship fitted with 5500 square feet of sail on two masts vs. the design operating speed. The most rapid payback occurs when the ship speed is 12 knots.

The benefits of sail-assist are not limited to rigs based on sophisticated technology. Figure 10 shows a Wind Ship designed rig for a small 150 dwt freighter for operation in developing countries where crew costs are relatively low. Figure 11 shows a Wind Ship rig developed for a vessel of 500 tons displacement. This rig is calculated to yield 37% fuel savings on the average.

In a recent independent assessment of the economics of sail-assist (Reference 5), Siyuan and Benford evaluated a 14 knot 18,000 dwt bulk carrier with 30,000 square feet of sail. Even under restrictive assumptions (e.g. extra crew and low fuel price), the sail-assist ship maintained an economic advantage over the pure motor ship.

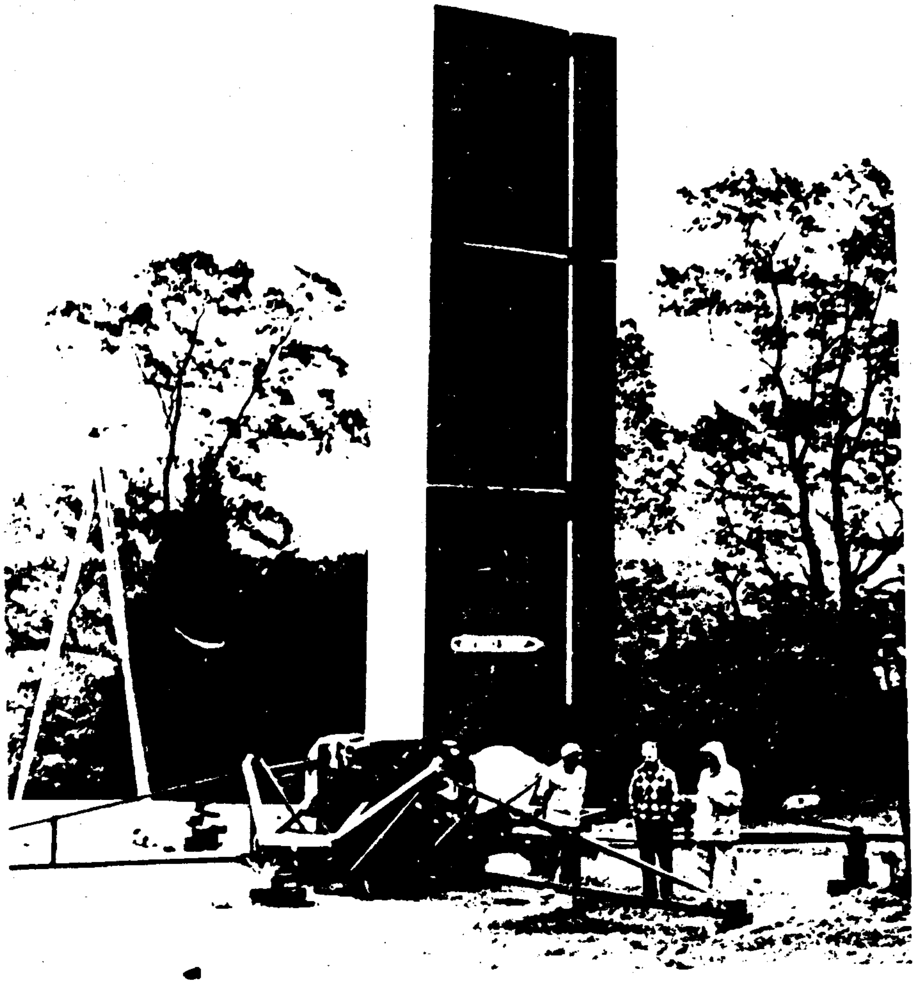


Figure 7

Demonstration of WIND SHIP's 300 sq. ft. Prototype Wing Sail (symmetrical airfoil with single flap) passively feathering without flutter in 25 knots of breeze, gusting to 40K - thus proving one of the several unique design features of this proprietary Sail Power Unit.

COMPARISON OF 3000 FT^2 CATRIG AND WINGSAIL

ON

MINI-CLASS SHIP

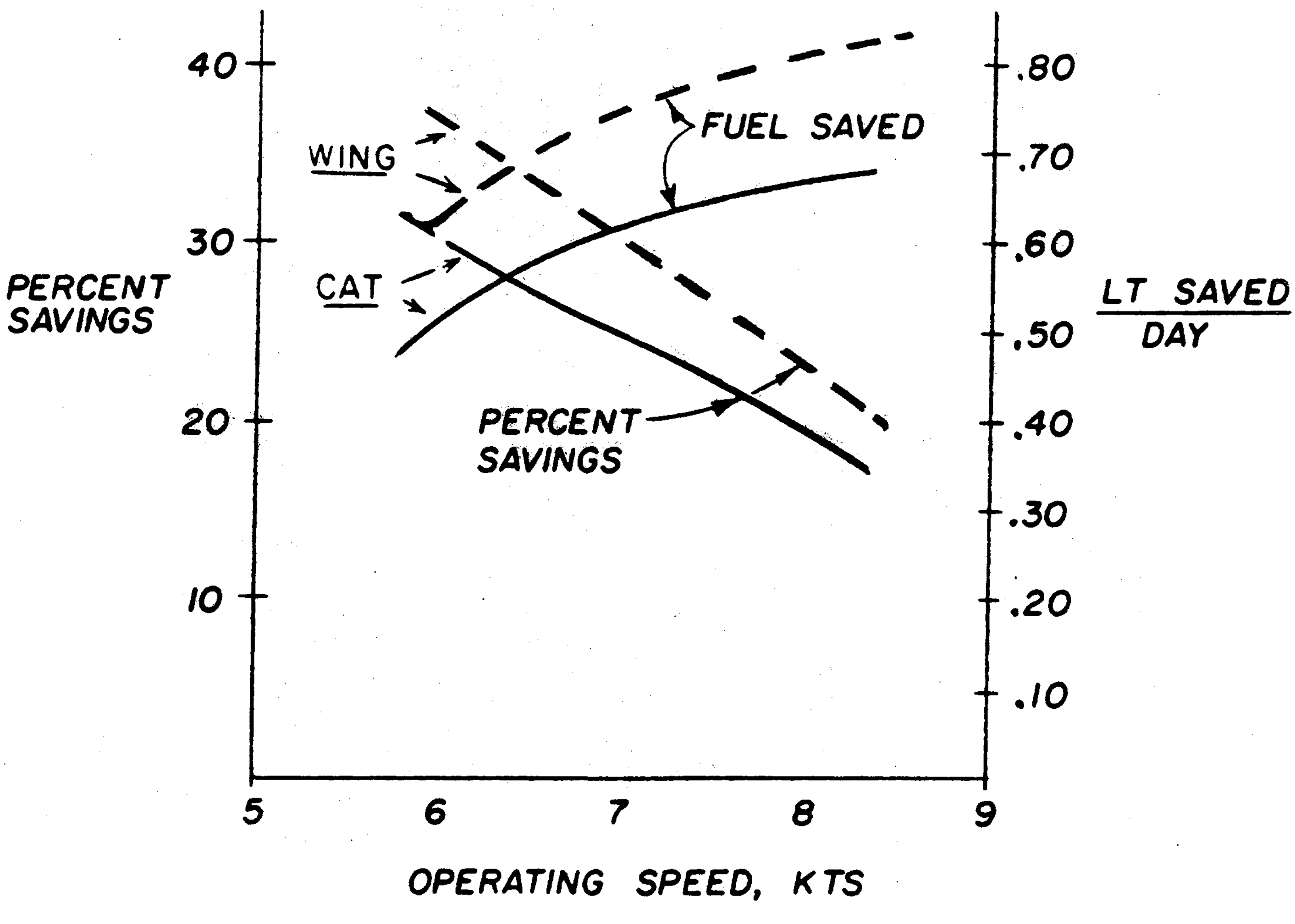


FIGURE 8

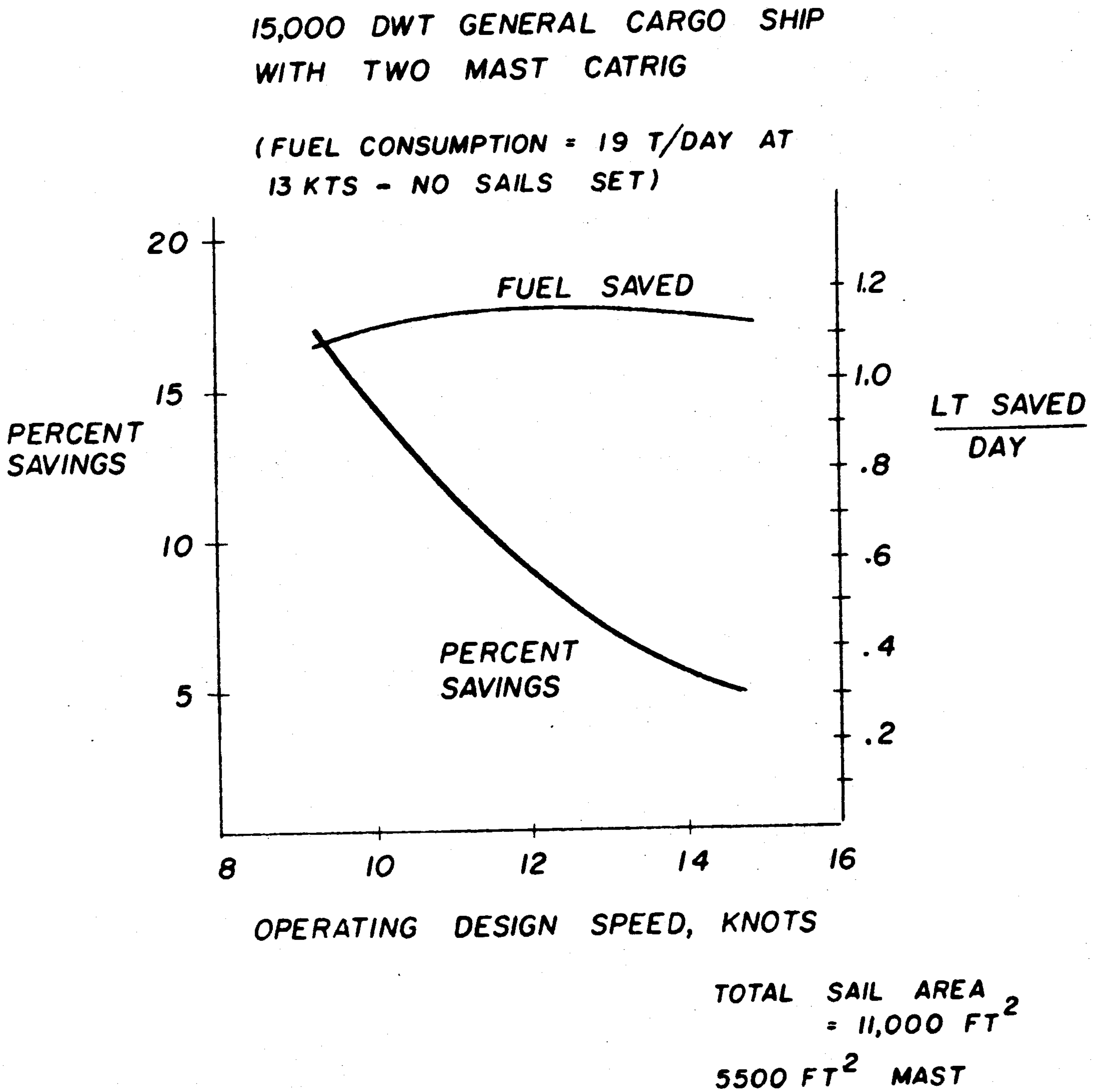
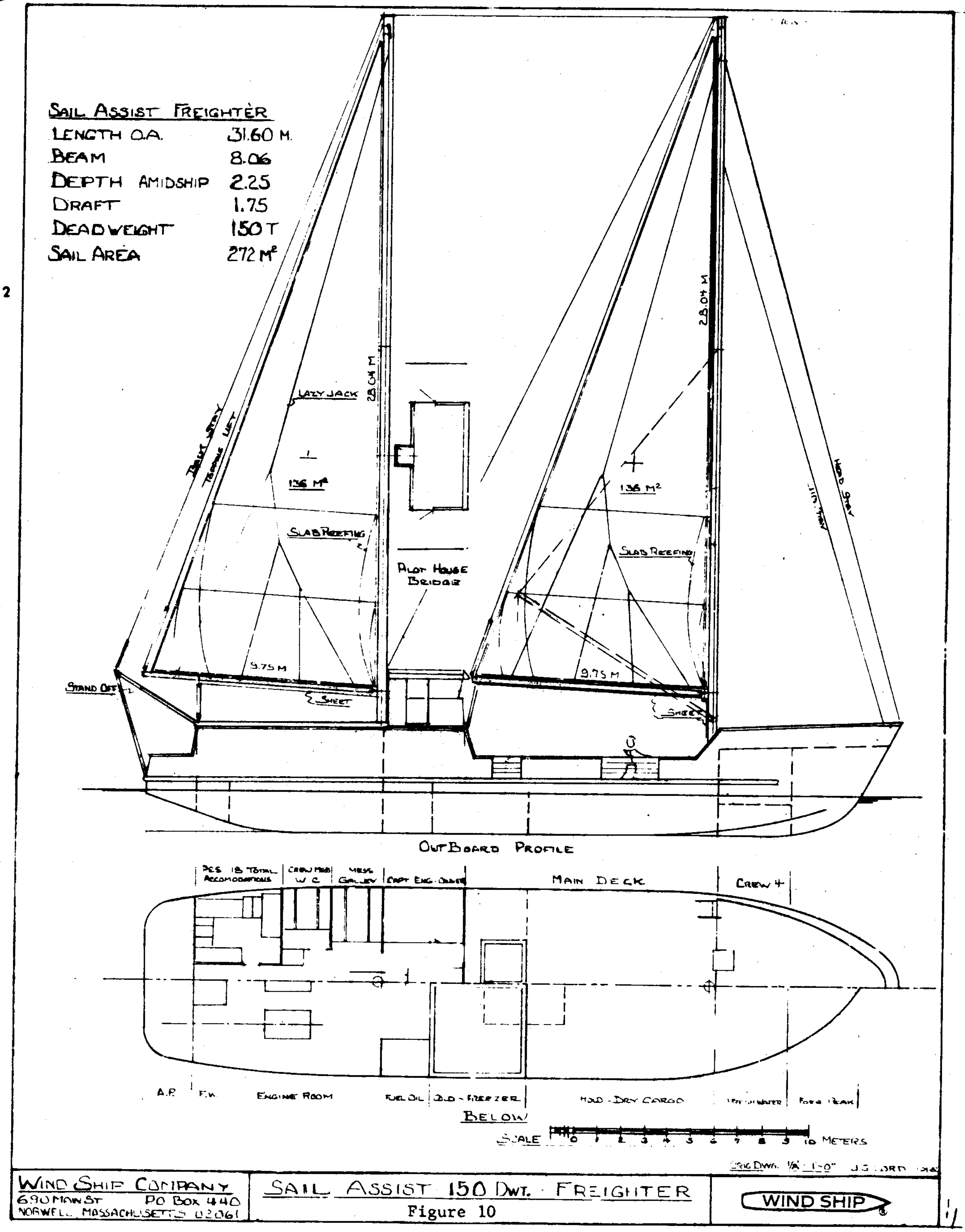

15,000 DWT GENERAL CARGO SHIP
WITH TWO MAST CATRIG
(FUEL CONSUMPTION = 19 T/DAY AT
13 KTS - NO SAILS SET)
20
15
10
5
PERCENT
SAVINGS
FUEL SAVED
PERCENT
SAVINGS
1.2
1.0
.8
.6
.4
.2
LT SAVED
DAY
8
10
12
14
16
OPERATING DESIGN SPEED, KNOTS
TOTAL SAIL AREA
= 11,000 FT²
5500 FT² MAST

FIGURE 9



SAIL ASSIST FREIGHTER
LENGTH O.A. 31.60 M.
BEAM 8.06
DEPTH AMIDSHIP 2.25
DRAFT 1.75
DEADWEIGHT 150 T
SAIL AREA 272 M²
28.04 M
LAZY JACK
136 M²
SLAB REEFING
PILOT HOUSE BRIDGE
9.75 M
STAND OFF
SHEET
OUTBOARD PROFILE
MAIN DECK
CREW 4
ENGINE ROOM
FUEL OIL
HOLD - DRY CARGO
FORE PEAK
BELOW
SCALE
METERS
WIND SHIP COMPANY
690 MAIN ST PO BOX 440
NORWELL MASSACHUSETTS 02061
SAIL ASSIST 150 DWT. FREIGHTER
WIND SHIP

Figure 10

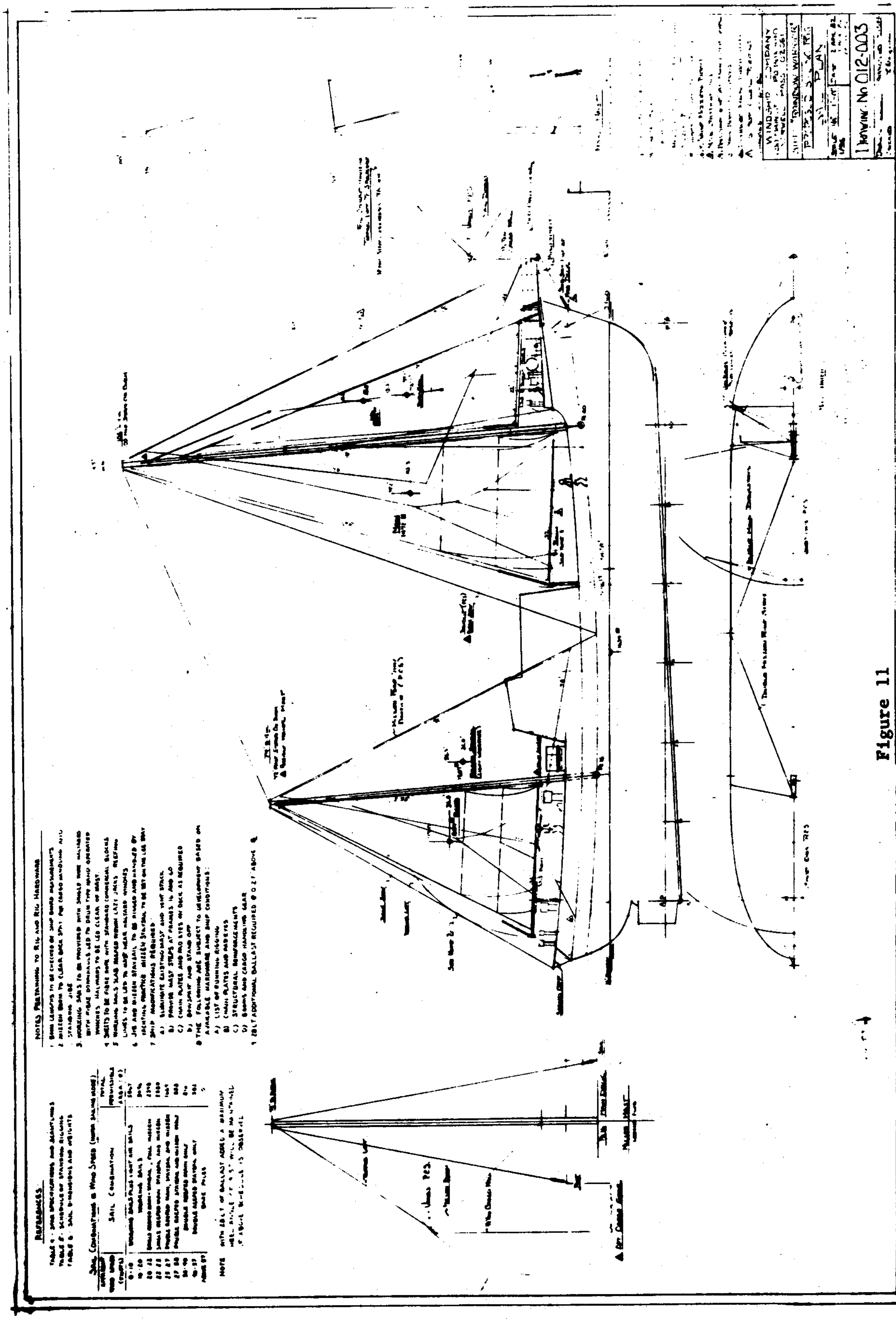


Figure 11

Proposed Sail Plan for 500 ton Trawler

ACTION

Sail-assist, even at today's fuel prices or lower, is an economically viable means of achieving large fuel savings and significant economic benefit. In the long run, the price of oil will inevitably rise more rapidely than other price indices. Not only will sail-assist become more attractive, but there will be added incentive to increase the fraction of total power generated by sail power units so that more ships operate in the "motor-sailing" range depicted in Figure 1. Now is the time for all thoughful shipowners to start planning to install sail-assist rigs on selected ships and to start gaining experience and confidence in their use. They will then be ready when the time comes to expand the application of wind power for ship propulsion in the years ahead to take full advantage of its tremendous economic potential.

The Author

Lloyd Bergeson is founder and President of Wind Ship Development Corporation and Chief Executive Officer of Wind Ship Company. He is a principal author of Wind Ship's report to the U.S. Maritime Administration - "Wind Propulsion for Ships of the American Merchant Marine". He has been General Manager of two major shipyards, the Quincy Shipbuilding Division of General Dynamics and the Ingalls Shipbuilding Corporation. Earlier, he directed the planning, cost engineering, material and production control activities of General Dynamics Electric Boat Division during the development of initial land-based nuclear prototype power plants and the world's first eight sea-going nuclear submarine prototypes, including U.S.S. NAUTILUS. He coordinated all of Electric Boat's activities in the development, design, and construction of the first POLARIS missile submarine, U.S.S. GEORGE WASHINGTON, and he directed Electric Boat's activities supporting the construction of the first British nuclear submarine, DREADNOUGHT. At Quincy he was responsible for developing and marketing the first 125,000 cubic meter LNG tankers sold in the world. As a shipbuilder, he has planned and/or directed engineering, costing, design, and construction of 20 different classes of major commercial and naval ships. In addition to marine consulting, he has provided consulting and management services for a wide variety of commercial development projects including solid state and cryogenic devices and equipment, jet engines, chemical process plants, and 100 MW nuclear power plants. A lifelong yachtsman, he has cruised and raced extensively over the past forty years and in 1978, concluded a single-handed passage under sail to Norway. He holds a B.S. degree in Naval Architecture and Marine Engineering from M.I.T. He is a member of the Society of Naval Architects and Marine Engineers and the American Bureau of Shipping.

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WIND PROPULSION FOR COMMERCIAL SHIPS

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Norwell, Massachusetts 02061

ABSTRACT

A systematic assessment of the technological and economic feasibility of sail power for commercial ships has been made with funding from the U.S. Department of Commerce, Maritime Administration (1). Various sailing rig concepts have been considered, and a wing sail, similar to an airplane wing mounted upright on the ship's deck, appears to offer better overall performance than cloth sail rigs. Based on parametric studies in which required freight rate is used as the economic measure of merit, sail-assist ships are found to compete favorably with conventional ships over a wide range of ship speeds. Sail-assist ships have sailing rigs of moderate size and in comparison with conventional ships, power plants of fractionally reduced size. The cost of such ships is found to be similar to the cost of conventional ships, since the saving in power plant cost offsets rig cost. At sea these ships burn 15 to 25 percent less fuel than conventional ships, and thus enjoy reduced voyage expenses. This advantage can be further enhanced by ship routing which makes use of real time weather information. The conceptual design of a 20,000 CDWT multipurpose wing sail ship indicates no major technical barriers to the development of sail assist hardware. Based on the overall findings of the study, an aggressive sail assist hardware development program seems warranted.

INTRODUCTION

The world shipping fleet consumes 730 million barrels of petroleum annually at a cost of approximately 30 billion dollars. This is about 3% of world petroleum demand. The price of marine fuels has multiplied more than 15 fold during the last decade and has become the largest component of operating costs for maritime shipping. Even in the face of these fuel cost increases, international oceanborne trade gives every indication of continued expansion. Shipowners, naval architects and governments of nations around the world have been moving rapidly

(1) Wind Propulsion for Ships of the American Merchant Marine, L. Bergeson et al, MARAD Report # MA-RD-940-81034, March 1981. (National Technical Information Service Document #PB 81-162455)

Note: This paper presented at Fifth Biennial Wind Energy Conference & Workshop (WWV), Sheraton Washington Hotel, Washington, D.C. October 5-7, 1981. Sponsored by Division of Wind Energy Systems, D.O.E.

to cut marine fuel costs through conservation or the use of alternate fuels. Wind propulsion is an alternate source of motive power, and the focus of this report.

RIG ALTERNATIVES

In order to focus attention on sailing rigs showing the most merit, a first order evaluation of the eight wind propulsion alternatives shown in Figure 1 was made. The wind turbines and Flettner rotor were eliminated from further consideration in the present study based on the following rationales: Wind turbines of the size required for marine propulsion have not been proven reliable in land based applications. When longevity problems which currently plague large wind turbines have been overcome, further examination of marine applications will be warranted. The Flettner rotor does show substantial potential for marine propulsion. However, the paucity of reliable aerodynamic data related to power input requirements provides little basis for system design and performance analysis and the development of such data was beyond the scope of the present study.

Conceptual designs were developed for the five sailing rigs shown in Figure 1A through 1E. Based on these designs, weight, cost and aerodynamic performance were estimated, and the rigs were ranked according to relative merit. The wing sail was found to be superior in terms of aerodynamic performance, initial cost and maintenance cost. It also rated best in operational and safety considerations. Of the other rigs examined, the stayed fore and aft, square and unstayed cat rigs ranked second, third and fourth in terms of initial cost effectiveness. The unstayed cat rig ranks best in terms of aerodynamic effectiveness, operational and safety considerations, but has slightly higher weight and maintenance costs.

The five rig concepts considered in the rig design study were all found to be technically feasible. Development can be accomplished through the adaptation and application of design, testing and analysis techniques which are presently available. The cat and wing sail rigs were chosen as representative of rigs likely to be built in the near future, and further investigation of these rigs is reported later in this paper.

INTEGRATED MODEL

A major part of the research conducted under the MARAD contract was the development of an integrated model; the objective being to systematically quantify the overall economics of sail propulsion so that the impact of ship size, ship speed and other primary parameters could be studied. This model comprises two sub-models, performance analysis and ship synthesis.

The performance analysis model applies to the full range of sail powering levels from conventional motor ship to pure sailing ship. It derives average ship speed and fuel consumption with the following procedure: Models of the hydrodynamic and aerodynamic forces and moments

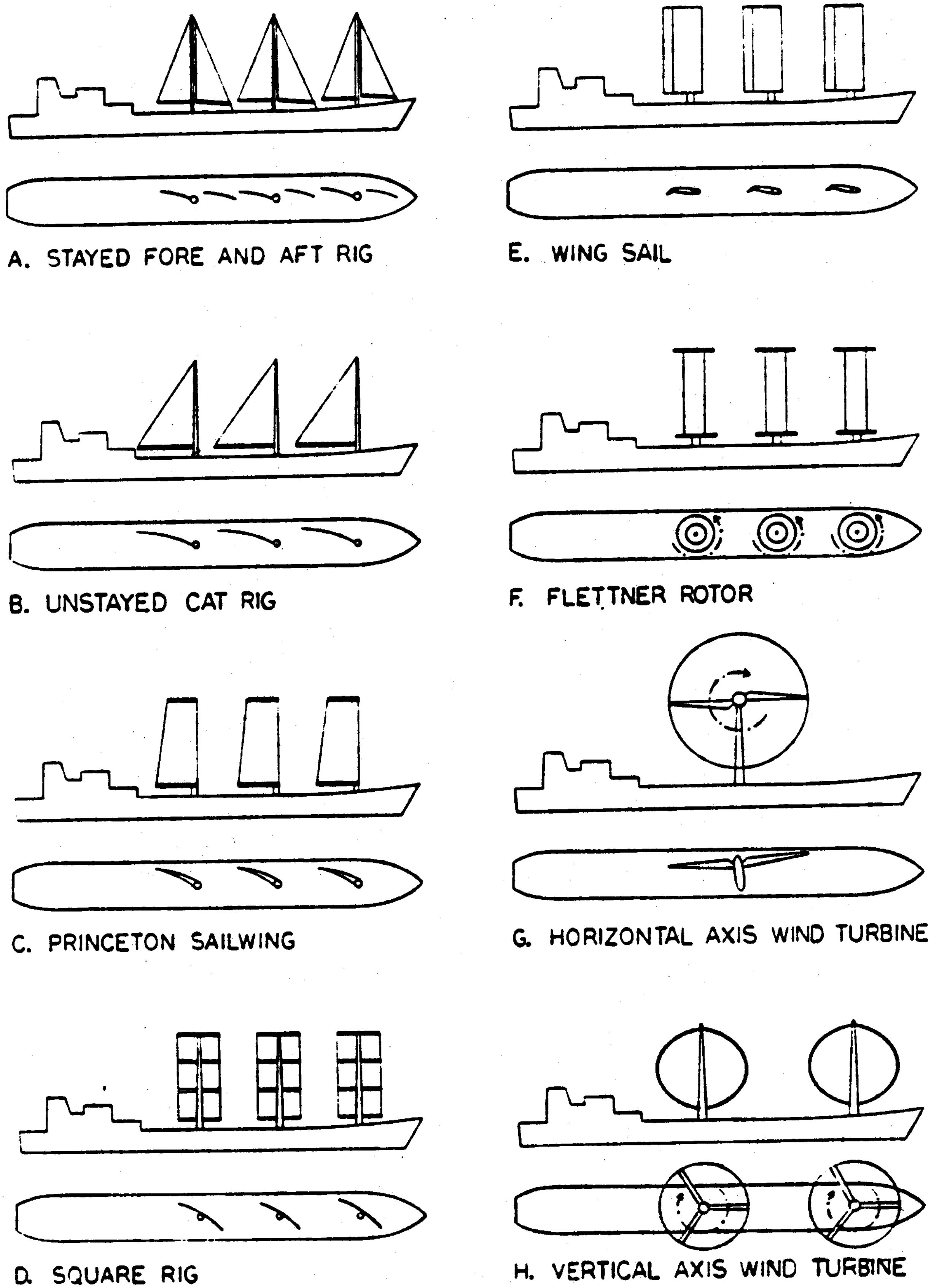


Figure 1 Rig Alternatives

acting on the ship are developed; ship speed and engine power setting for given wind conditions are determined; finally a statistical model of the route wind is applied to yield average voyage speed and fuel use.

The ship synthesis procedure synthesizes principal characteristics of hull and sailing rig, and estimates weight, stability, building cost, and operating and voyage expenses. These are combined with the performance predictions to determine the economic merit of the ship using required freight rate (RFR).

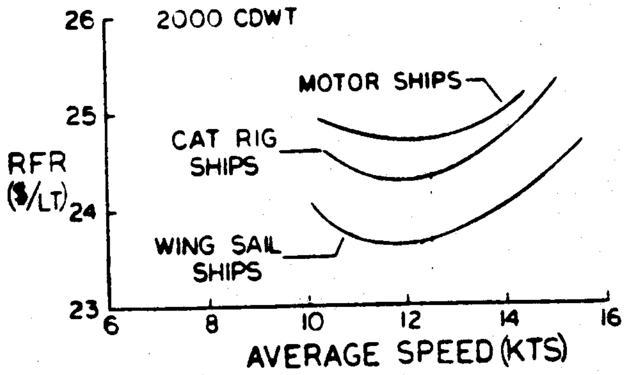
RFR is the freight rate that a shipowner must charge to cover operating expenses and provide an appropriate return on the capital invested. The RFR's used in the study are based on shipbuilding and operating costs prevailing in the U.S. These costs are two to three times those prevailing elsewhere in the world, and in fact most U.S. flag shipowners receive substantial subsidy from the U.S. government. Since the fuel costs in the U.S. are at or below those prevailing elsewhere, these RFR's show less sensitivity to fuel savings than world fleet RFR's. Thus the results of the study should be a conservative indication of the potential benefit of sail assist for world shipping economics.

PARAMETRIC STUDY

Using the integrated model, a parametric study was performed to determine the general effects of ship size, ship speed, and hull and rig parameters. Motor ships, cat rig ships and wing sail ships ranging in size from 2,000 to 38,000 CDWT (cargo deadweight, long tons) were analyzed. Based on an analysis of opportunities for sail assist in the U.S. fleet, a ship size of 20,000 CDWT was chosen for detail study. Hull and rig parameters were optimized for a 20,000 CDWT wing sail ship, as were hull parameters for an equivalent motor ship. Given these two ships, the sensitivity of the relative economics to various parameters was determined. The principal findings developed in this exercise are presented below.

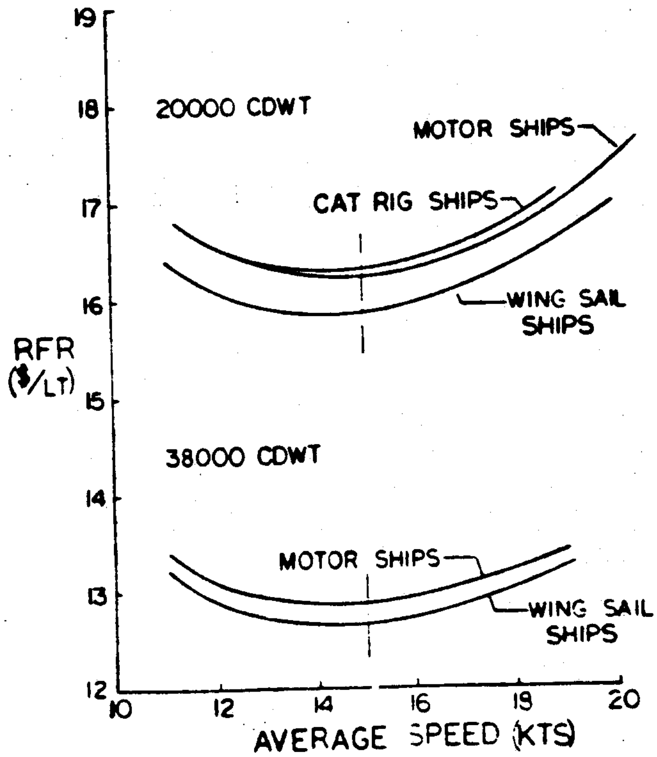
<u>Ship Size and Rig Type</u>. Figure 2 presents RFR versus average speed for three ship sizes. The wing sail ships have lower RFR's than the cat rig ships. This result is consistent with the merit ratings reported earlier. The economic advantage of sail-assist is greater on the smaller ships. This is primarily due to the fact that sailing rig cost per unit area increases for larger rigs, while cost per horsepower and specific fuel consumption decrease for larger engines. At present fuel prices, cat rig ships are competitive up to 20,000 CDWT, while wing sail ships are competitive up to at least 40,000 CDWT.

<u>Ship Speed</u>. The study considered motor and sail-assist ships with powering levels suitable to achieve average speeds ranging from 10 to 20 knots. Over this speed range, sail-assist ships show a nearly constant economic advantage over motor ships. Thus, there is no economic barrier to the viable operation of sail-assist ships at speeds competitive with conventional motor ships.



2000 CDWT Ships
at 12.5 knots average speed

	Fuel Cons. (LT/Year)	RFR ($/LT)
Motor Ship	1,333	24.73
Cat Rig	1,098	24.28
Wing Sail	1,005	23.69



20,000 CDWT Ships
at 15 knots average speed

	Fuel Cons. (LT/Year)	RFR ($/LT)
Motor Ship	7,543	16.25
Cat Rig	6,684	16.31
Wing Sail	6,118	15.88

38,000 CDWT Ships
at 15 knots average speed

	Fuel Cons. (LT/Year)	RFR ($/LT)
Motor Ship	10,510	12.90
Wing Sail	8,627	12.67

Figure 2: Required freight rate and fuel savings for three ship sizes. RFR is in dollars per long ton per round trip. Since RFR is sensitive to ship hull form, these have been optimized to minimize RFR. Sailing rig parameters are not optimized, thus RFR savings shown are conservative estimates. All ships operate in a wind distribution with 16 knot average speed, and equal directional probability.

Fuel Savings. As shown in Figure 2, the sail-assist ships save 18 to 25% of the annual fuel consumption. Optimization of rig parameters to minimize RFR saves 2 to 5% more fuel at present fuel prices. If a sail-assist ship is designed to have an RFR equal to the motor ship and save the maximum amount of fuel, the fuel savings are greater.

Engine Size. In addition to fuel savings, the power generated by the sailing rig allows a reduction of engine size similar to the percentage fuel savings. For a given vessel size and sailing rig, the rig power output remains essentially constant, independent of average ship speed. Thus, as higher fuel prices force lower average speeds and smaller engines in both motor ships and sail-assist ships, the fuel savings and engine size reduction will be proportionately greater.

Ship Cost. The cost of sail-assist ships is not substantially different from that of the same size and speed were found to be es- is offset by the savings associated with a reduction in machinery size. The extent to which this offset occurs depends on ship size and rig efficiency, but the 20,000 CDWT wing sail ships were found to cost essentially the same as the equivalent motor ships.

Hull Form. The economically optimum hull forms of sail-assist ships and motor ships of equivalent size and speed were found to be essentially the same. Thus no extreme excursions of hull form from current practice are indicated. When a motor-sailing ship and a motor ship are both subjected to the same draft limit, the economic advantage of sail propulsion is not diminished. Also, cargo density does not have a significant impact on the economic comparison between the motor-sailer and the motor vessel.

Optimization of Rig Parameters. Figure 3 shows RFR vs. average speed for 20,000 CDWT motor ships and wing sail ships. The wing sail ships have a 210 foot air draft measured above the ballast waterline. Shown within the dashed box are the effects of rig parameter variations used to determine the optimized rig parameters. For a 14 knot average speed, the minimum RFR is $16.26/LT with 4 wings of 9000 square feet each designed to operate in winds up to 40 knots. The RFR of the 14 knot motor ship is $16.93/LT. Thus the economic advantage of the wing sail ship is $.67/LT or 4% of total shipping cost. The wing sail ship burns 26% less fuel, and has a main propulsion engine which is 30% smaller than the motor ship's 6018 horsepower engine.

Air Draft. At present fuel prices, economically competitive sail-assist ships do not require excessive air drafts. The optimum air draft was found to be 210 feet for the 20,000 CDWT wing-sail ship. However, an air draft limitation of 170 feet (which allows access to most major ports) only increases the RFR to $16.31/LT and retains most of the advantage of sail-assist. For the 170 foot air draft ship, the power output of the rig has been kept close to the output of the taller rig by maintaining most of the sail area on shorter masts, and by increasing the operational design wind speed to 45 knots. This ship has five wings of 6000 square feet each, and forms the basis for the conceptual design presented later in this paper. It saves 24% of the motor ship fuel consumption and has a main engine 27% smaller.

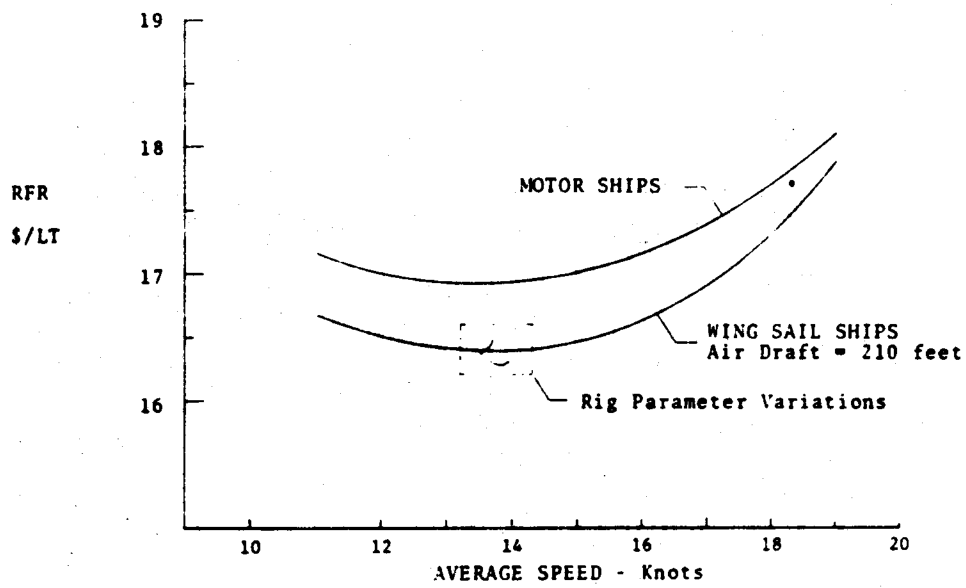


Figure 3: RFR vs. average speed for 20,000 CDWT motor and wing sail ships of optimized hull form. The impact of rig parameter variations is shown in the dashed box.

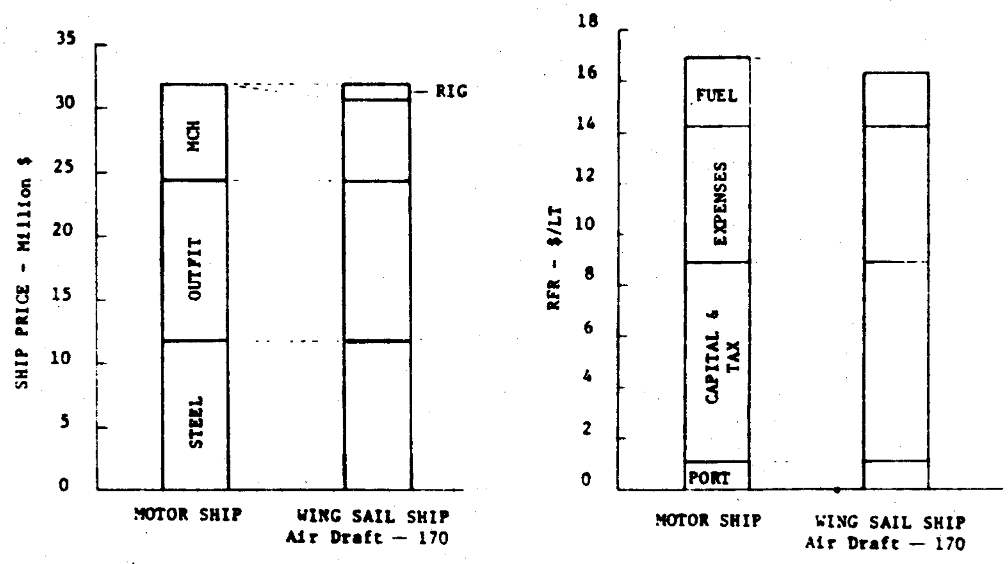


Figure 4: Ship price and RFR breakdowns for 20,000 CDWT wing sail ship and an equivalent motor ship. Ship Speed equals 14 knots.

Figure 4 presents RFR and construction cost breakdowns for the 170 foot air draft ship and the motor ship.

Wind Conditions. Sail-assist preserves its economic advantage at surprisingly low average wind speeds. For instance, the 170 foot mast height ship described above maintains an economic advantage down to an average wind speed of 10 knots, even though it was designed for an average wind speed of 16 knots.

Manning. The economic viability of sail assist is sensitive to increments in ship manning levels. Given U.S. labor costs, a 20% increase in manning would at present fuel prices negate the economic advantage of a 20,000 CDWT wing sail ship. It is clear that any relaxation of the requirement for low maintenance and automation in the sailing rig would have an adverse effect on the economic advantage of sail-assist.

CONCEPTUAL DESIGN

In order to study the implications of fitting a sailing rig to a merchant vessel of popular size and application, the conceptual design of a 20,000 CDWT multi-purpose dry cargo vessel was developed. Such a ship illustrates the co-existence of sailing rig and cargo handling gear. The 170 foot air draft ship from the parametric study served as the starting point, and the design effort concentrated on novel features and constraints associated with the presence of the rig. Elements of ship configuration not related to the sailing rig were not treated in detail, and would vary depending on the particular application. On this basis the design should be indicative of how sail-assist could be applied to merchant vessels in general.

Figure 4 illustrates the design that was developed. The ship has five wing sails totaling 29,280 square feet of sail area, and an air draft of 171 feet. One of the principal design compromises necessitated by the wing sail installation is in the arrangement of cargo handling gear, which must be located clear of the tail-swing circles of the wings. Consequently, the derricks which would typically be positioned at the ends of the cargo hatches are situated on each side. Such an arrangement still allows all parts of each hatch to be served, and both ends of all hatches to be worked simultaneously. When handling cargo, the wing sails will be locked in the athwartship position.

Figure 5 illustrates the conceptual arrangement of the wing sails. The wings have a NACA 0015 airfoil section, with a 25 percent chord plain flap divided into three spanwise segments and adjustable through plus or minus 40 degrees. The sails are stepped in bearings which allow unconstrained 360 degrees rotation. The center of rotation is forward of the quarter chord point in order that the sails be self-feathering when allowed to rotate freely in their bearings. In normal operation, trimming gear and flap actuators operate in concert to trim the wings for optimum sail-assist. When winds exceed the design wind speed of 45 knots, the trimming gear is allowed to freewheel, the flaps are set to neutral position, and the wings feather passively into the wind. The wing sails are remotely controlled from the bridge, and there should be no difficulty in designing a control

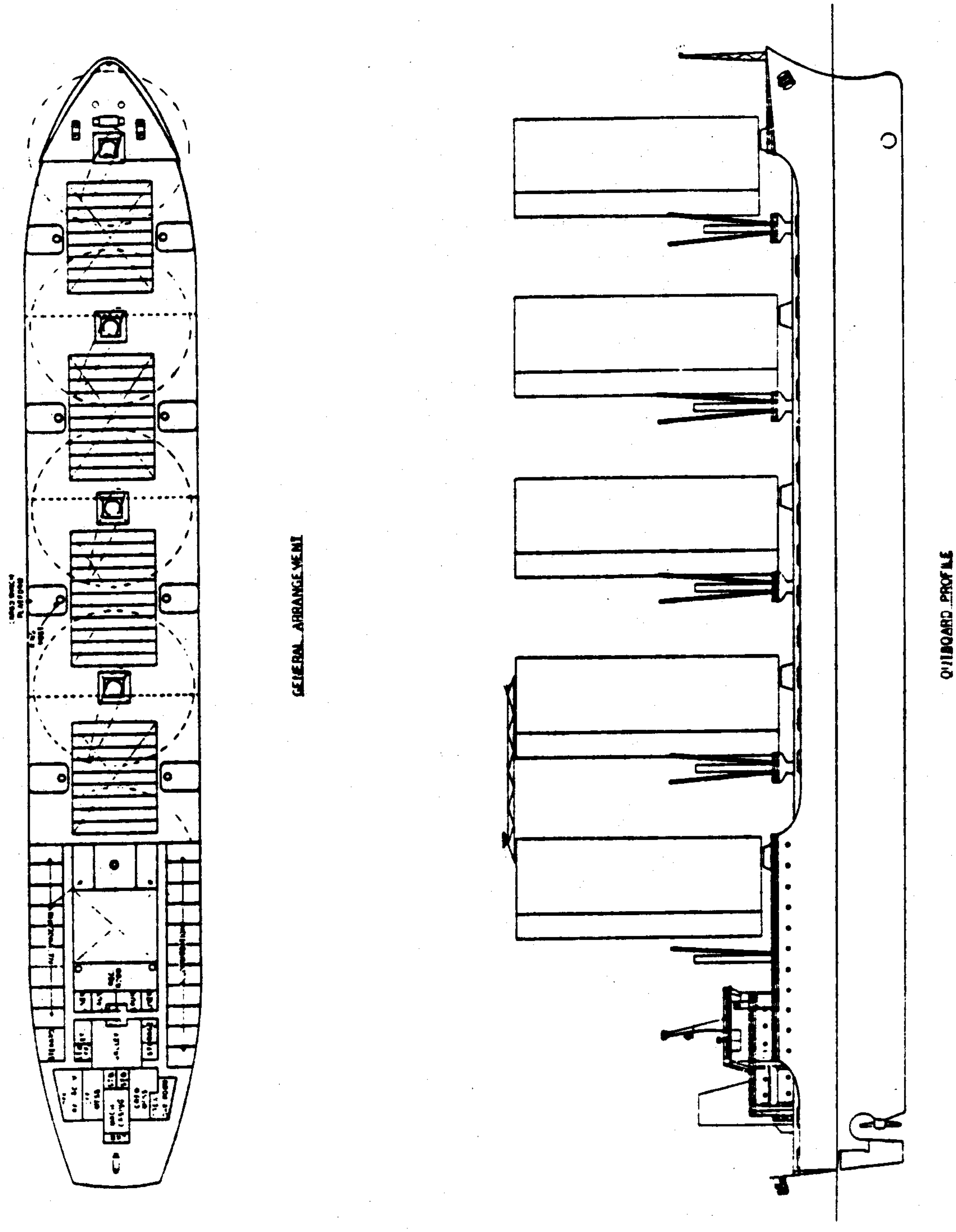


Figure 4 General Arrangement and Outboard Profile of the Conceptual Design: Length, B.P. 523', Beam 81.1', Draft 32.4', Displacement 28,565 LT, CDWT 20,000 LT, Bale Cubic 1,000,000 cu. ft., ME horsepower 5,060, Average rig horsepower 1629, Average Speed 14 knots.

system which is sufficiently automated that no increment in manning would be necessary. The total rig weight of 240 tons (including hull reinforcing, etc.) is offset in part by the reduction in propulsion machinery weight. The ship's stability is only slightly affected by the rig, and no problem with achieving sufficient stability is forseen.

A controllable pitch propeller and bow thruster are commonly installed on conventional vessels of this size, and are specified for this ship. The controllable pitch propeller should accommodate the range of speed thrust conditions anticipated. With the bow thruster, low-speed maneuverability should not be a problem.

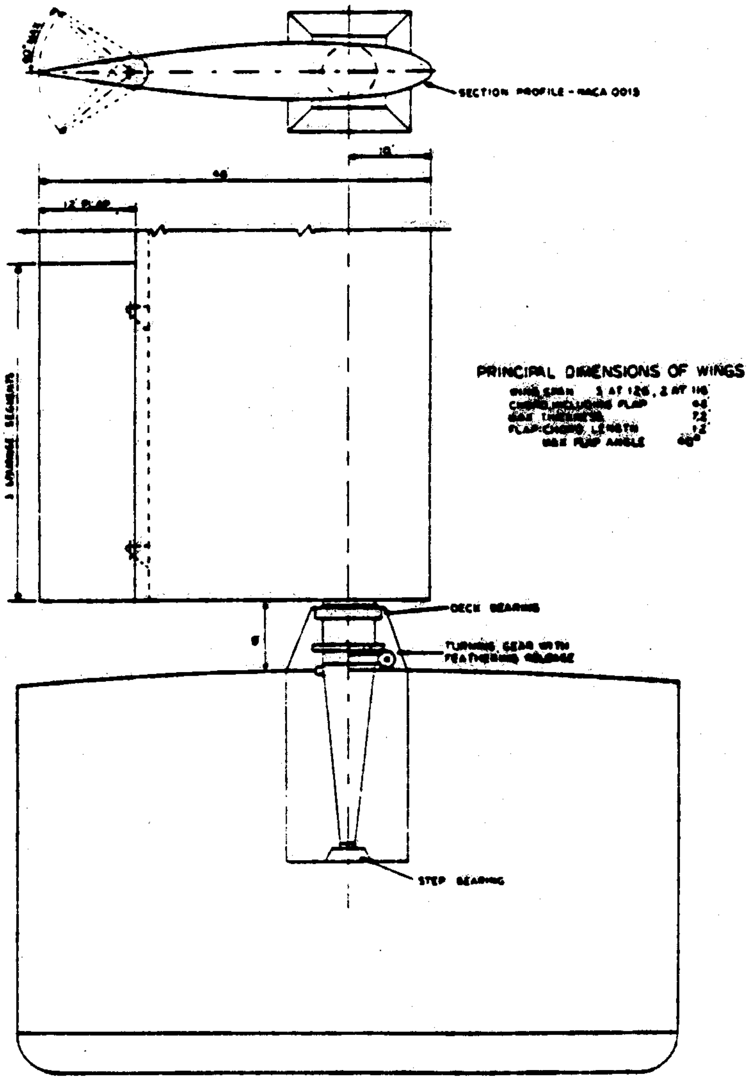


Figure 5: Wing Sail Arrangement

WEATHER ROUTING

Sailing ships have long taken advantage of knowledge of winds and currents to improve passage performance. A weather routing study was performed to determine the benefit achieved by applying weather routing to a sail-assist ship. Two 20,000 CDWT ships were selected from the parametric study for this analysis: the 170 foot mast height wing sail ship and the equivalent motor ship. North Atlantic weather was simulated using a Monte Carlo simulation technique with statistics following those given by pilot charts. A dynamic programming approach was used to select the optimal route for each passage from a grid covering most of the navigable waters between New York and the English Channel. The yearly average voyage statistics derived from these simulations indicate that by using weather routing, a sail-assisted vessel may expect to increase its effective voyage speed by three percent over the course of a year contributing to a decrease in RFR from $16.31/LT to $15.96/LT. The weather routed motor ship will experience only a marginal improvement in RFR from $16.93/LT to $16.92/LT. Thus, the RFR spread between the two ships increases from $.62/LT to $.96/LT when both make use of weather routing; and the combination of sail assist and weather routing can be expected to save about 6% of total shipping cost for 20,000 CDWT ships.

SAIL ASSIST OPPORTUNITIES

An evaluation of U.S. Merchant Marine fleet forecasts indicates that the majority of ships to be constructed in the next decade would benefit from sail propulsion. Small and medium size tankers are the best candidates, as sail would cause little or no complication to normal operation. General cargo ships are also good candidates and the number of these ships forecast should provide incentive for development of sailing rigs which double as cargo handling gear. Container and partial container ships might benefit from sail-assist, but the potential of sail propulsion in liner trades will remain uncertain until the effects of sail assist on passage time variance are quantified.

Of the U.S.-foreign trade routes, the North Atlantic and North Pacific routes have the highest average wind speeds. Caribbean trade routes show wind conditions only slightly above average, but a large quantity of trade in small ships and favorable wind directions make these routes candidates for sail assist as well.

While the topic of retrofitting sailing rigs to existing vessels was not treated directly, some inferences can be made. The similarity between optimum motor and sail-assist hull forms indicates no major problem with a mismatch between rig and hull. Many existing ships have older power plants whose specific fuel consumption is higher than those in the study. Such considerations work to the advantage of an existing motor vessel that is retrofitted with a sailing rig. A factor working to the disadvantage of retrofit is engine size. Because of the additional power provided by the sailing rig, a retrofitted ship will probably be somewhat overpowered for its hull form.

This should not be a major problem as an engine use strategy which takes cognizance of the problem can be developed. A review of present merchant fleets indicates that significant opportunity exists for the retrofit of existing vessels.

OVERALL CONSIDERATIONS

Fuel Savings. Assuming it practical to apply sail-assist to 50% of the world fleet, the circa 1980 potential annual savings would be on the order of 70 million barrels and over $2 billion. The savings for the U.S. flag fleet would be 2.8 million barrels and approximately $85 million annually.

Technology. The findings of this study indicate that no major technical barriers exist to the introduction of sail-assist for the world's shipping fleet. In addition, sail-assist is compatible with the present technologies of ship hull and machinery design.

Development. Sailing rig development, including testing at sea of a full spectrum of rigs can be budgeted in terms of millions of dollars and two to three years as opposed to the billions of dollars and longer time frame associated with other high technology energy projects. The potential benefit for the U.S. fleet alone would justify a multi-million dollar development program.

Regulations. Current rules and regulations do not provide for commercial sailing ships. Since the economic benefits are clear it is certain that the application of sail-assist to commercial ships will spread. Therefore, consideration should be given by classification societies, regulatory bodies and professional societies to addressing the problem of developing appropriate rules. This should be done in such a way that rule development will proceed in concert with the spreading application of commercial sail.

WIND SHIP RETROFIT ANALYSIS MODEL

Introduction:

Wind Ship has developed a Sail-Assist Retrofit Analysis Model (see flow chart next page). This computer-based model is used to assess the economics of installing a sailing rig on a given ship. The given ship can be an existing ship for which retrofit is being considered, or a new ship for which the owner wants to know the incremental economics of adding a sailing rig. Using a voyage scenario and parametric ship description supplied by the owner, the model is used to determine the net annual return for a given sailing rig retrofit. The calculations take into account the effects of engine use strategy, cargo deadweight reduction due to rig weight, rig maintenance and repair, and fuel savings. A more detailed description of major components of the model follows.

Route Wind Analysis:

Wind statistics for the given voyage scenario are derived from a magnetic tape data base of weather statistics which covers all oceans of the world. The data tapes were supplied by the U.S. National Climatic Center, and compile the data from years of shipboard and weather station observations. The data is broken down to statistics for every 5° by 5° square of latitude and longitude, and by month. Average wind speed, wind speed distribution, and wind direction distribution relative to the ship's heading are derived according to the wind statistics in each square which the ship will transit, the length of the course through each square, and the average heading in each square. This statistical description of the wind is then passed to the Performance Analysis portion of the model.

Performance Analysis

The Performance Analysis Program predicts average ship speed and fuel consumption for a motor ship, motor-sailing ship, or pure sailing ship operating in the wind statistics derived by the wind analysis. Additional outputs include heel angles, leeway angles, and optimized sail trim for a full range of wind conditions. Included in the optimized sail trim are the effects of reefing (or feathering for wing sails) in high winds exceeding the rig design wind speed. Engine use strategy is also accounted for, and is specified either as a constant engine power output or as a target ship speed. A target ship speed strategy is usually used, with target speed varied to give the ship speed for most rapid rig payoff.

Retrofit Model:

The Retrofit Model takes as input the characteristics of the existing ship, and a description of the desired sailing rig. This description of the ship with rig is passed to the performance model along with a specified engine use strategy. The performance model passes back ship speed and fuel consumption, which are combined with the logistics of the voyage scenario to determine annual transport capacity and annual "variable" costs (fuel cost + port fees + rig maintenance and repair). The computation of annual transport capacity takes into account the loss in CDWT capacity associated with rig weight. By specifying a range of engine use strategies, the relationship between annual transport capacity and annual cost is determined over a full range of speeds between slow steaming and maximum speed. This set of calculations is performed once for the ship without a rig, and the results form the benchmark for evaluation of rig alternatives being considered for the ship. Subsequently, this analysis is repeated for each retrofit rig option.

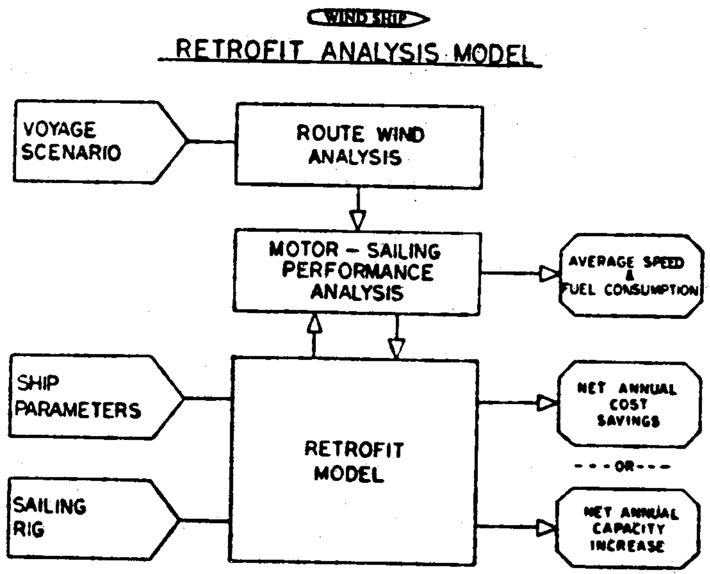
The fuel saving performance of the retrofit ship is easily determined by comparison of fuel consumption rates with those of the benchmark ship. A comparison of the annual costs to those for the benchmark operated at the same annual transport capacity gives the net annual return generated by the sailing rig.

In addition, using the existing ship operating at its normal service speed as the benchmark, detailed results are presented for the retrofit ship operating at:

1. equal annual transport capacity with reduced annual cost;

2. equal annual cost, with increased annual transport capacity.

The annual cost savings, or the increased cargo capacity, is the "net annual return" associated with the particular rig being studied. Using these results along with the estimated cost of construction and installation, the overall economics of any proposed sailing rig can then be determined.



WING SAIL COMPARISON

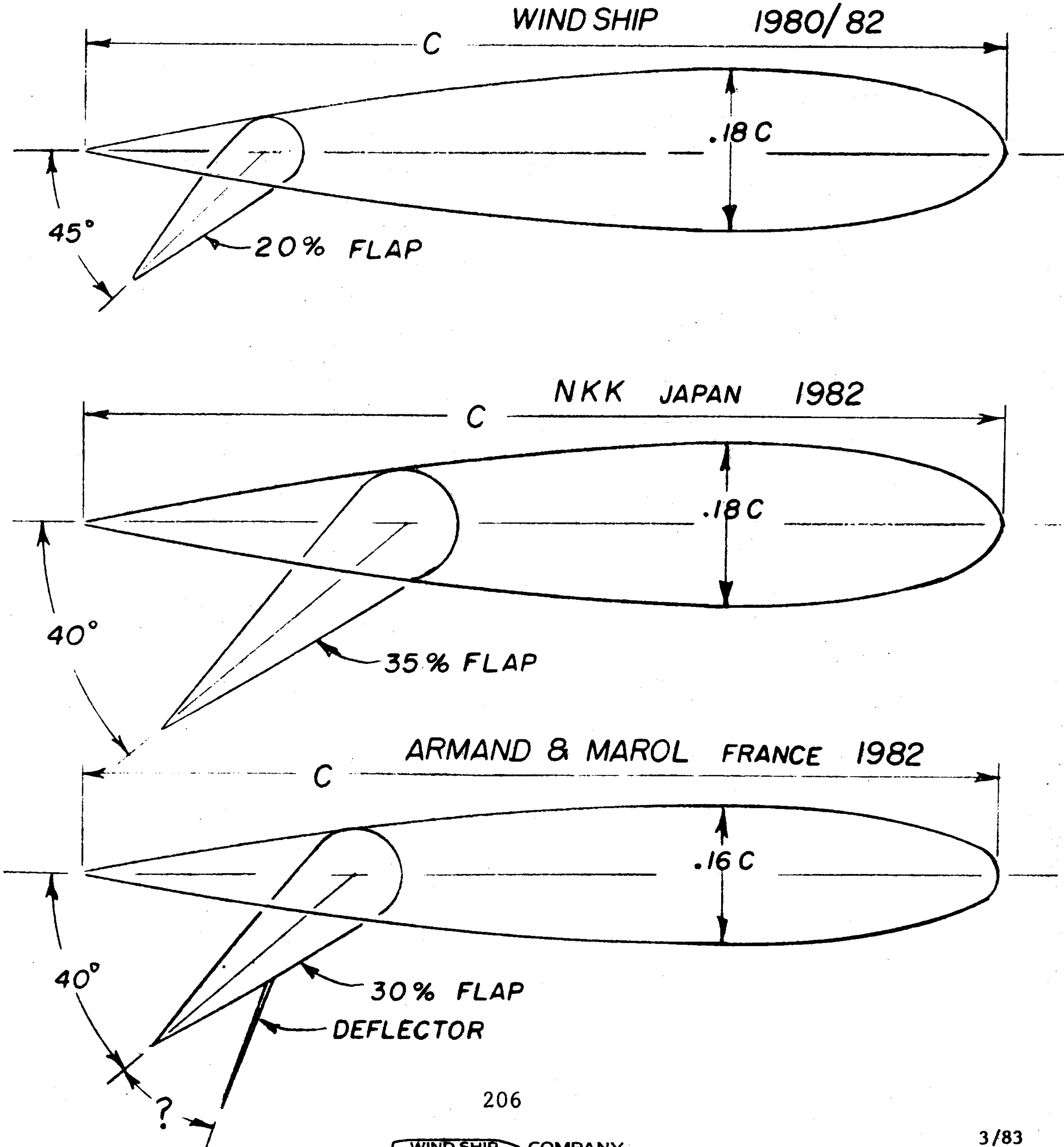
	1980/82 WIND SHIP (1)	1982 NKK (2)	1982 ARMAND & MAROL (3)
SECTION CHARACTERISTICS	NACA 0018 20% FLAP	NACA 0018 35% FLAP	MODIFIED SNIAS 16% 30% FLAP, 15% DEFLECTOR
ASPECT RATIO	2.86	3.00	2.76
TEST SCALE % OF FULL SCALE CHORD LENGTH	1/3	1/40	1/50
$C_{L\,max}$	2.0	1.8	2.4
MAX. REYNOLDS # FOR TEST	4,500,000	416,000	540,000
PASSIVE FEATHERING	PROVEN	NOT CONSIDERED	NOT CONSIDERED
RETRACTION SYSTEM	TESTED	NOT CONSIDERED	CONSIDERED

(1) WIND PROPULSION FOR SHIPS OF THE AMERICAN MERCHANT MARINE, Lloyd Bergeson et al, MARAD report #MA-RD-940-81034, March 1981 and SAIL-ASSIST ALTERNATIVES FOR AUXILIARY PROPULSION, Lloyd Bergeson, prepared for Motor Ship 5th International Marine Propulsion Conference in London on March 4, 1983.

(2) SAIL EQUIPPED MOTOR SHIP "SHIN AITOKU MARU" AND STUDIES ON LARGER SHIP, T. Watamabe et al, presented at the ANCIENT INTERFACE XII SYMPOSIUM, October 31, 1982.

(3) AERODYNAMICS OF SAIL ASSISTED PROPULSION OF COMMERCIAL SHIPS: A PRELIMINARY STUDY, J. L. Armand and P. Marol, presented at the ANCIENT INTERFACE XII SYMPOSIUM, October 31, 1982.

COMPARISON OF WING SAIL SECTION CHARACTERISTICS



SAIL RETROFIT ANALYSIS DATA SHEET

Ship ______________________ Registry ______________________

Builder ______________________ Year Built ______________________

SHIP CHARACTERISTICS:

- Length between perp ______ ft or m
- Beam ______ ft or m
- Draft: full load ______ ft or m, ballast ______ ft or m
- Block coefficient ______
- Displacement: full load ______ LT, ballast ______ LT
  - Light ship ______ LT
  - Deadweight (full load) ______ LT

    Fuel ______ LT; Msc. Dwt ______ LT; CDWT ______ LT
- Roll period ______ seconds and maximum roll angle ______ degrees
- Power plant: type ______ Single or Twin ______
  - Manufacturer ______________________ Model ______________________
  - Maximum continuous rating (each) ______ HP at ______ RPM
- Reduction gear: type ______________________ reduction ______________________
- Propeller(s): single or twin ______________________ No. of blades ______

  diameter ______ ft or m pitch ______ ft or m

PLANS & TABLES:

- Outboard profile
- Inboard profile
- Deck plan
- Midship section
- Trim & stability booklet (or, if not available, GM ______ ft or m)

SAIL RETROFIT ANALYSIS DATA SHEET (cont.)

FUEL SPECIFICATIONS:

Sea Fuel ______________ Average Price ______________ as of ________

Port Fuel ______________ Average Price ______________ as of ________

TYPICAL VOYAGE SCENARIO:

• Port name	______	→	______	→	______ →
• Bridge height restrictions	______		______		______
• Port time	______		______		______
• Sea time		______		______	
• Port fuel rate	______		______		______
• Port charges	______		______		______
• Cargo carried each leg: (LT)		______		______	
• Average speed logged: (knots)		______		______	
• Main engine fuel consumption (LT/day)		______		______	
• Auxiliary fuel consumption (LT/day)		______		______	

(continue as necessary)

MISCELLANEOUS:

• Average annual layup time ________ days/year

• Information prepared by ______________________ date __________

A WINDMILL THRUSTER EXPERIMENT

Jeffrey Dunlap, John Nickelsen, David Luke and Thomas Watts
University of South Florida
Department of Chemical and Mechanical Engineering

ABSTRACT

The windmill catamaran known as the Winded Bull was a result of a senior project design class taught at the University of South Florida. A four member team designed and built the vessel in 16 weeks with help from the other class members on the hull construction. The vessel is 14 feet 10 inches (4.5 m) long, has a beam of 8 feet (2.4 m), supports a 10 foot (3.0 m) mast with a 15 foot (4.6 m) diameter wind turbine, and is driven by a 2 1/2 foot (76 cm) water propeller. The vessel and water propeller are constructed of wood and the wind turbine of fiberglas and carbon fiber over a foam core. With the exception of the hulls, all components were designed and simulated for performance using various computers available at the University. Instrumentation has not yet been installed, but the vessel has achieved travel in all directions relative to the wind.

INTRODUCTION

In our present day world where microelectronics hurl us into our future, a rudimentary study of energy conversion is frequently scorned as passe'. However, in many cases energy conversion techniques being employed today in the commercial fishing industry are moving this industry towards a position of being less than marginally profitable. Until recently new high technology developments have not been put to use to benefit the commercial fishing industry. A welding of some of these new developments with a re-evaluation of older techniques shows promise for a revitalization of the fishing industry.

This paper is the result of a project design course taught in the Chemical-Mechanical Engineering Department of the University of South Florida by Professor John W. Shortall III. As the title of the paper suggests, this project is an experiment. Even more, this project will be the first phase of a protracted series of experiments aimed at gathering information about different means of using wind power to propel seagoing vessels. The goals of this project were: first to design and construct a water-borne experimental platform; second: to design and construct a wind energy extractor-thruster system; third: was to test the completed system.

It may be logically argued that experimental data taken from a small vessel such as the one designed for this project is of no consequence to the commercial fishing fleet. This argument gains more bearing upon the realization that the vessel cannot perform any commercial fishing operations. The experiment gains its validity from the uniqueness of the complete concept. As many forums have brought to light, it is very nearly impossible to compare the performance data of different vessels using different propulsion techniques. Such comparisons become more difficult when different fisheries are involved.

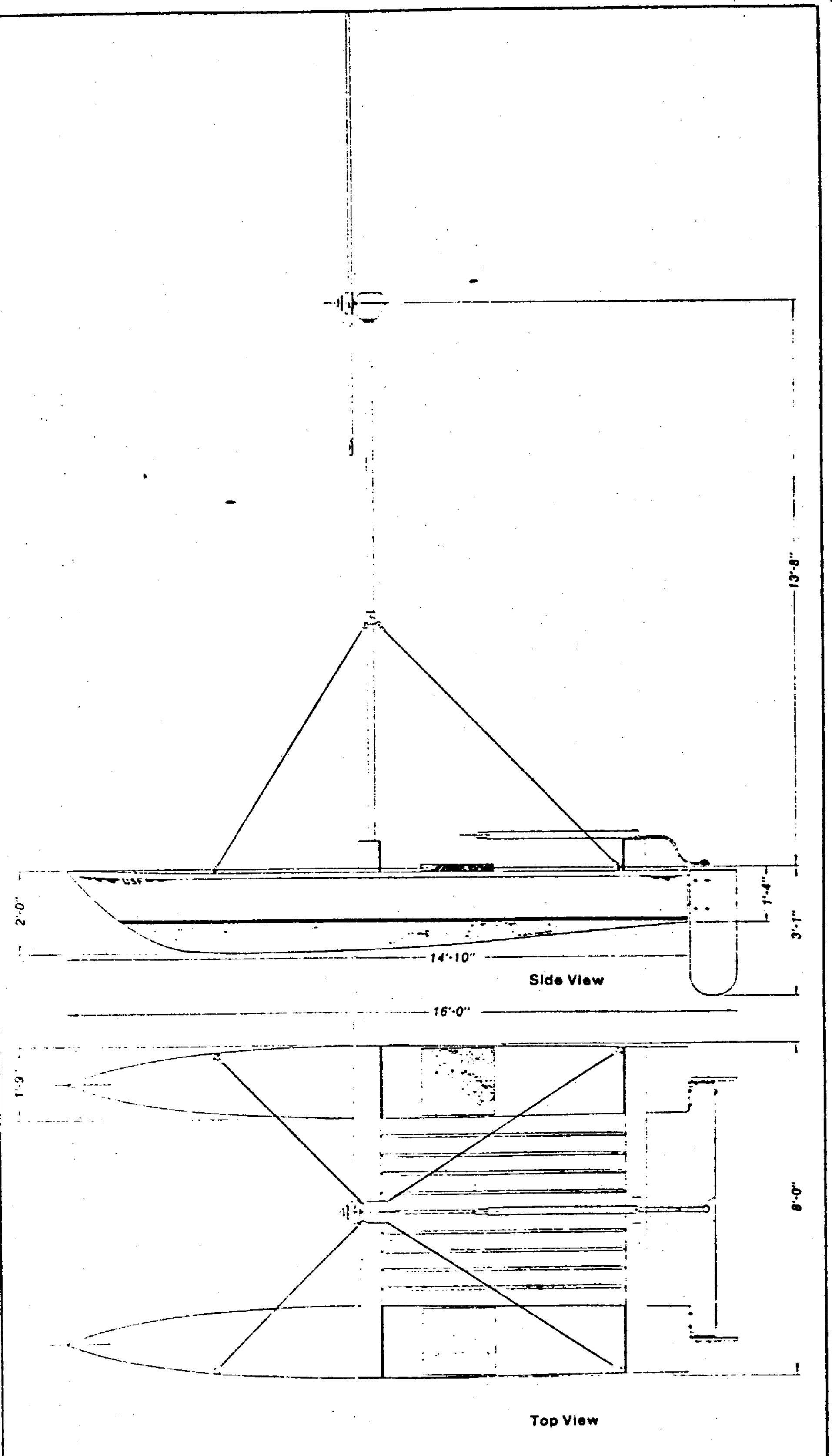
This project will allow the comparison of several different wind energy extractors and thrusters on the same vessel. These devices will include, a Flettner rotor, windmills of several types, wing sails, conventional sails and engine power. Without attempting to extrapolate data from vessel to vessel, qualitative conclusions will be able to be drawn concerning the appropriateness of using different energy extraction devices for particular uses.

VESSEL DESIGN AND CONSTRUCTION

The first step in the design of the vessel was to pick a design technique. Based on the suggestion of Professor Shortall a technique elaborated on by the Gougeon brothers [6] was chosen for its simplicity as well as its ability to develop an easily built low cost vessel. A catamaran configuration was chosen primarily due to its inherent initial stability. This is of crucial importance because of the desire to change the rigging and thereby the loading on the vessel from experiment to experiment. The catamaran configuration has several other characteristics which are beneficial to this experiment. The absence of a large central keel allows for higher thruster efficiency due to the lack of disturbance in the thruster slip stream. The two hulls tend to accelerate the water towards the thuster due to a funneling effect between the hulls. In addition, the vessel may be significantly lighter with the same stability because of the lack of heavy ballast in the keel.

The design technique is based on of a designer fabricated 1/12 scale model and a few basic calculations. The scale model is built of balsa from simple sketches following the construction procedures to be used on the full scale version. This technique proved to be ideally suited for an amateur designer. The dimensions of the vessel were arrived at from several considerations. The length was limited by the amount of wood donated to the project by Professor Shortall. The beam was determined by a combination of the allowable trailer width in the state of Florida for transporting the vessel and a rule of thumb relating length to beam for catamarans. A design displacement for the vessel was based on an expected weight of the propulsion rig. Several models were built based on an overall length of 15 feet (4.6 m), a beam of 8 feet (2.4 m) and a maximum displacement of 1200 pounds (544 kg). An iterative discussion process between the design group and Professor Shortall was used to develop the model. Dimensions for the full size vessel were taken from this model and scaled up. An artist's conception of the design chosen is shown in Figure (1 & 2).

Construction of the vessel required the 18 people in Professor Shortall's Project Design II class, five weeks to complete. The Gougeon brothers named the construction method, the compound plywood technique. Professor Shortall named it the tortured plywood technique. By the end of the first week of construction the students had renamed the technique "the tortured student method". In fact, the procedures and operations required to build the hulls were very easy to accomplish. The hulls and structural members of the vessel are wood, coated with epoxy laminating resin and painted. The completed weight of the hulls, crossmembers , and



Top and Side View of Thruster-Powered Catamaran

Figure 1

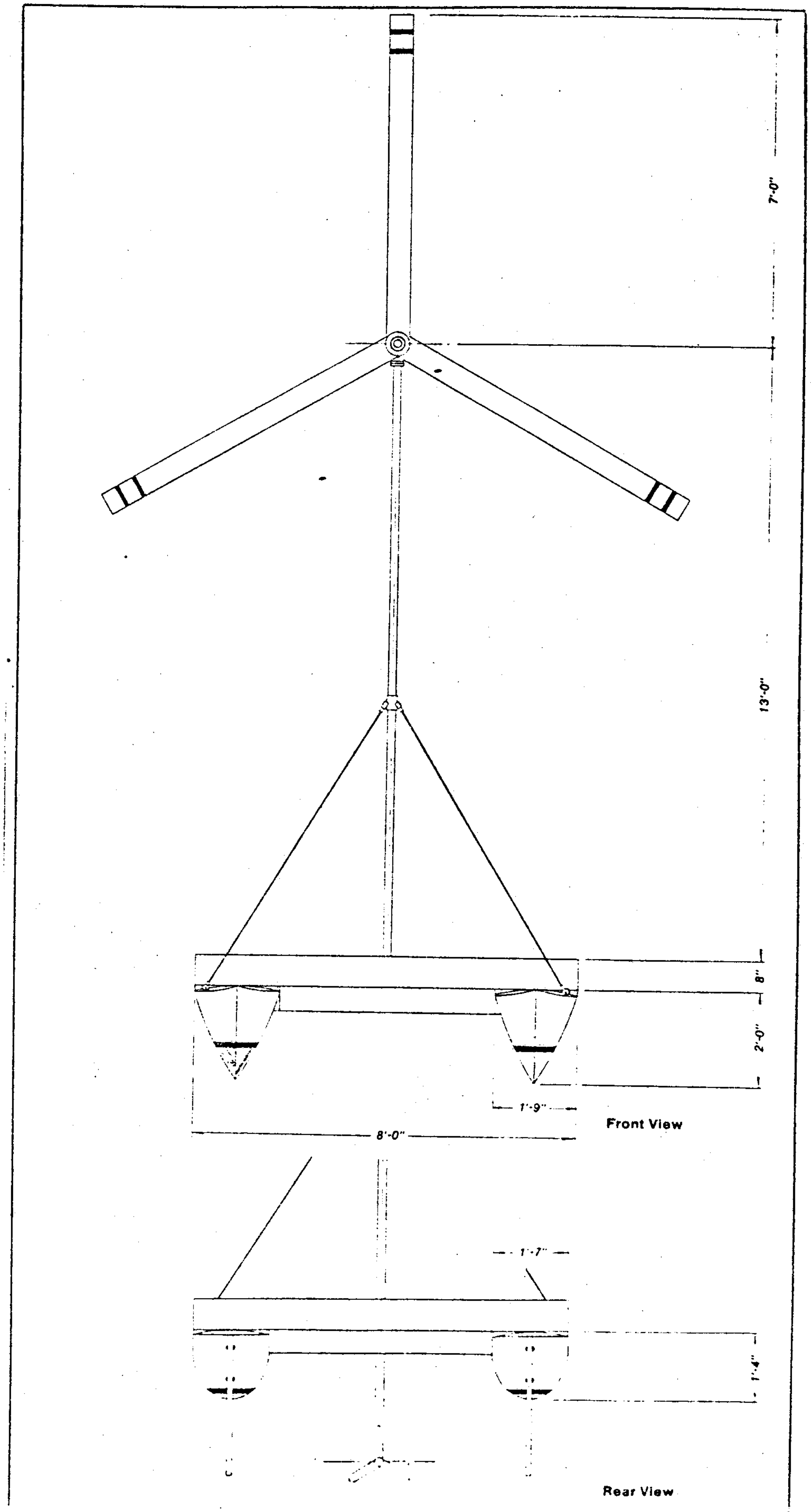
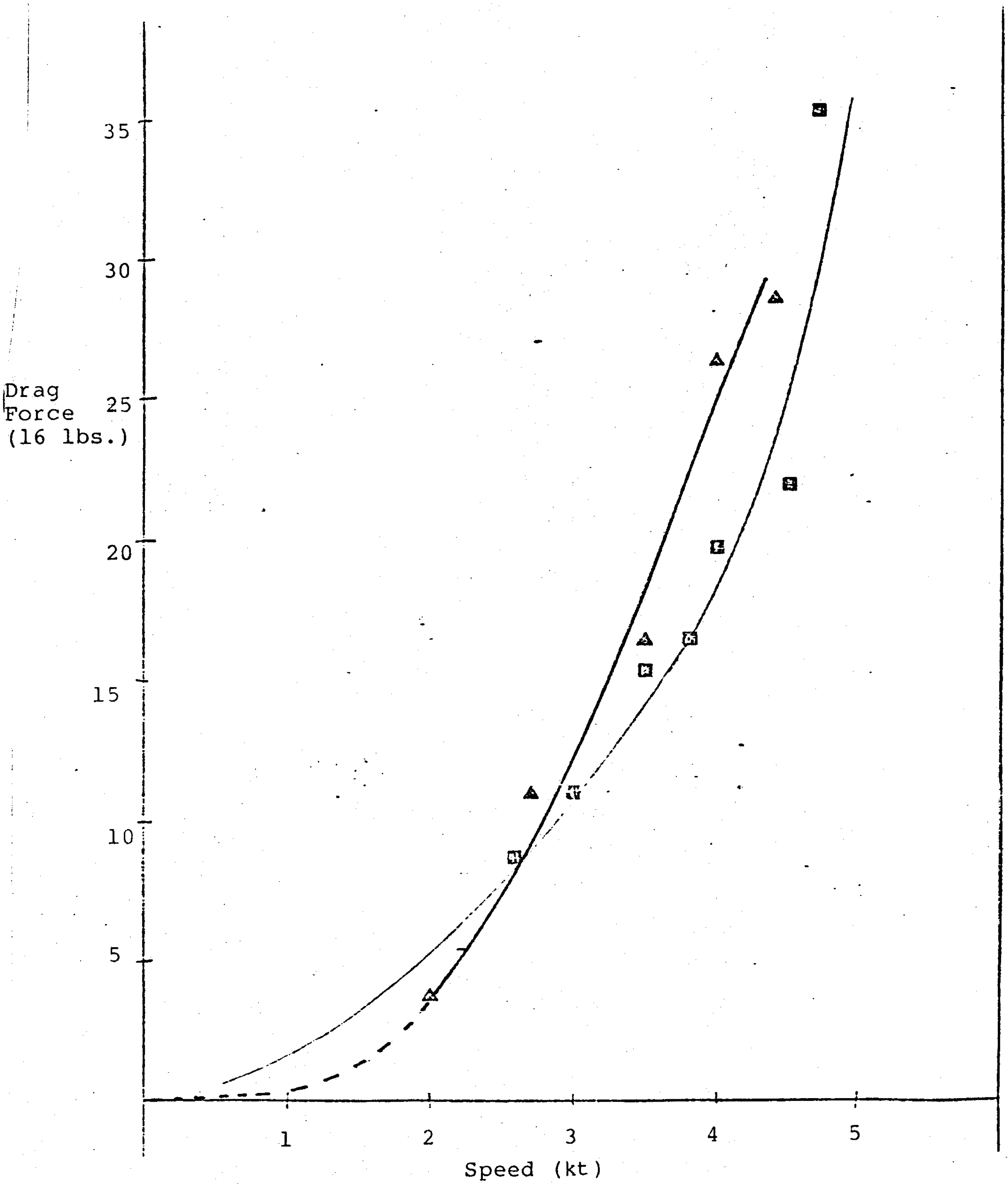


Figure 2

Onboard wgt. - (175, 185) = 360 lb
Unloaded draft - 3"
Loaded draft - 6"

Windspeed - 5 - 10 mph



▲ (-) - Windspeed was on lower end of above scale

▩ (-) - Windspeed had increased, vibration of the rudders began at 3.5 kt

** - Below 2kt the catanary of the 50' nylon line would pull the boat witnout registering on the scale

Figure 3

between hulls platform is 360 pounds (163 kg). The weight difference between the hulls was slightly greater than one pound (453 g).

After completion of the vessel, a rudimentary drag test was performed. The results of this test were used to check assumptions made during design of the propulsion system. Figure (3) displays these results in graphical form. The graph was generated by towing the vessel in a lake, approximately 150 feet (45.7 m) behind a power boat. The two curves represent two runs, each with a different orientation to the wind. True wind speed varied from four to eight knots during the test runs. The vessel drag was measured with a spring scale. Due to the low drag force recorded up to a vessel speed of approximately 4 knots, it was felt that the craft could be easily moved by the designed propulsion system.

DRIVE TRAIN DESIGN AND CONSTRUCTION

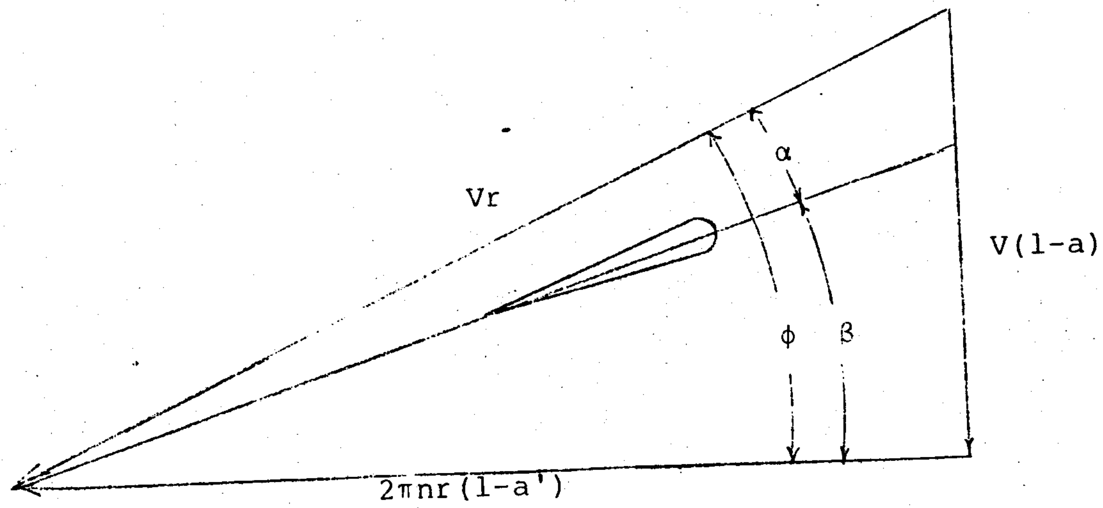
The design of the drive train for the project had five primary constraints. Paramount among these was the requirement that friction losses through the system be minimized. Secondly, there was very little money available for purchasing components, so cost was important. Thirdly the wind turbine had to be able to rotate, without restriction, around the vertical drive axis. The fourth constraint was that of safety. The final consideration was transportability. This required that the drive train system be quickly and easily assembled or disassembled.

The first three constraints were taken care of in one move. An inboard/outboard drive unit was purchased from a marine salvage yard. The purchase price of ten dollars fit well into the project budget. In addition, the unit provided the bevel gears required for shaft orientations. The gears and shafts were mounted on roller thrust bearings and needle bearings. These bearings, once cleaned and lubricated, assured minimal frictional losses. The purchased drive unit housing was reworked and modified to be used as the bearing mounts for the wind turbine drive system. The modifications to this housing also allowed the wind turbine its free rotation about the vertical axis. Placement and control of the wind turbine as well as the water propeller were the means chosen to assure safe operation of the vessel. The horizontal axis of rotation of the wind turbine was elevated by the mast, leaving a minimum of 44 inches (112 cm) between the blade tips and the boat deck. This provided safe head clearance for the crew in their normal seated position. A handle to permit directional control of the wind turbine gave the crew speed control of the vessel for safe maneuvering. The water propeller was mounted on a folding drive leg. This prevented severe damage to the vessel in the case of grounding. In addition, folding of the leg in an emergency would cut off the transmission of power to the water propeller. The folding drive leg also allowed the vessel to be easily transported.

The mast is affixed to the vessel by triangular guy wire rigging. With this rigging removed, the mast and drive shaft may be lifted free of the vessel as one unit. Removal of the mast and folding of the drive leg permit the vessel to be transported on a standard trailer. The drive system as a unit is very workable but heavier than was hoped.

BLADE DESIGN

The wind turbine was designed using modified blade element theory [3]. This theory was applied at 21 stations along the length of the blade.



where; n = angular velocity (rps)
r = radius to station
a,a' = interference factors
V = wind speed + boat speed

Figure (4) shows the cross sectional view of the blade. The vectors $2\pi nr(1-a')$ and $V(1-a)$ are the present winds which add together to form the apparent wind, Vr. From geometry and trigonometry we see that:

$$\alpha = \phi - \Theta$$

$$\text{Tan } \phi = (1-a)V \;/\; (1-a')2\pi nr$$

Then as shown in reference 3:

Thrust -- $dT/dr = B*b*.5* *Vr*(Cl*\cos\phi - Cd*\sin\phi)$

Torque -- $dQ/dr = B*b*.5* *Vr*r*(Cl*\sin\phi + Cd*\cos\phi)$

where: dT/dr = elemental thrust
dQ/dr = elemental torque
B = number of blades
b = chord length
ρ = density of air
Cl = lift coefficient

Cd = drag coefficient

The hundreds of calculations necessary for this type of analysis made the use of a computer necessary. A computer program was written by the author for a Tektronix 4051 computer. This program used the modified blade element theory to generate thrust and torque characteristics, along with the geometric pitch required, at each station. Using the trapezoidal rule, the overall blade characteristics were found. Rather than making an attempt to calculate the interference factor (a), the program iterated through the possible values from 0 to .5 [3].

The symmetrical NACA 0015 airfoil was chosen based on its lift and drag characteristics and for structural reasons. It was necessary that blade tip deflections be kept to a minimum. The symmetrical airfoil had a moment of inertia about the chord line larger than that of an asymmetrical airfoil. To readily obtain lift and drag coefficients, polynomials (see appendix B) describing the lift and drag curves [5] were generated using a Prime 750 , one of the Engineering College's main computers.

Once the program was completed, a trial and error method was used to determine the parameters of the wind turbine blades. Final design of the blades is as follows:

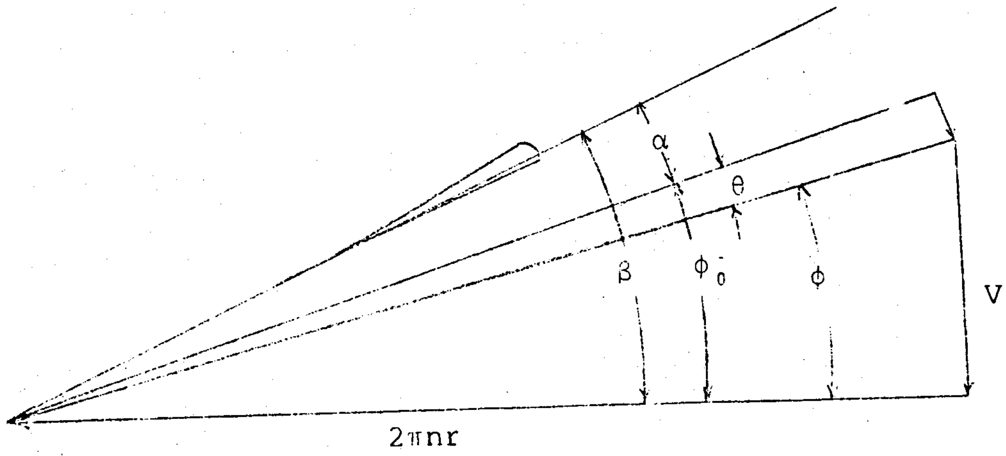
Number = 3 blades
Length = 7.5 feet (2.3 m)
Chord = 6 inches (15.2 cm)
Linear Twist = 44 degrees

Due to mechanical reasons, it was decided that the pitch of the blades would be variable during assembly only.

The blades were constructed of styrofoam and fiberglas. Full size aluminum templates of the airfoil cross section were made. Then the blades were cut out of a styrofoam block which was 8 feet (2.4 m) in length. This was accomplished using a hot wire technique. This technique uses a nickel nichrome wire drawn taut. A variable voltage is applied across it. The variable voltage permits varying the temperature of the wire. Using the aluminum templates as a guide, the desired shape is cut out of the block of styrofoam with the wire.

The styrofoam blades were then wrapped with a wet lay up of fiberglas. This fiberglas was made longer than the blades to allow clamps to be attached. Each blade was then placed back in its mold and 40 pounds (18 kg) of stress was applied to it using the clamps and suspended weights. The whole system was then sealed in a plastic bag and a vacuum was pulled in the bag until the resin had cured. This procedure was performed a second time on each blade only the mold was not used. Finally the blades were coated with a filled epoxy and sanded to a close approximation of the airfoil cross section. Balancing of the blades was accomplished using lead inserts where necessary.

Design of the water propeller was done using the vortex theory [2].



where; Θ = induced flow angle
V = boat speed

Figure 5 shows the cross sectional view of the blade. The vectors V and $2\pi nr$ are the present winds and Vi is the induced flow. These vectors add together to form the apparent wind. If we define the variable x as:

$$x = r/R$$

where: r = radius to station
R = radius of propeller

and define the blade solidity as:

$$\delta = B*b*R/A = B*b/ R$$

where: B = number of blades
b = chord length
A = area of propeller disk

Then from simple momentum theory we could show that the induced flow angle Θ can be defined as:

$$\Theta = \beta - \phi / 1+(8*x*\sin\phi / \delta*ao)$$

where: ao = lift slope for an infinite aspect ratio

continuing the geometry, we see that :

$$\mathrm{Tan}\ \phi = V / 2\pi nr$$

and

$$Vr = 2\pi nr*\cos\Theta / \cos\phi$$

Once again we arrive at the torque and thrust as follows:

Thrust --- $dT/dr = B*b*.5* *Vr\verb|^|2*(Cl*\cos\phi_o - Cd*\sin\phi_o)$

Torque --- $dQ/dr = B*b*.5* *Vr\verb|^|2*r*(Cl*\sin\phi_o + Cd*\cos\phi_o)$

where: dT/dr = elemental Thrust
dQ/dr = elemental Torque
ρ = density of water

In the same manner as the wind turbine, the theory was applied at stations along the length of the blade. Ten positions along the blade were analyzed and elemental thrust and torque values were obtained . Again graphs of elemental thrust and torque verses blade positons were constructed and overall characteristics were obtained by taking the integral of these curves using the trapezoidal rule. This analysis, also, was performed on a computer. The author wrote programming describing the vortex theory, as described here and in reference 2, for an Apple II+ computer.

The airfoil section used was a 3R10. This is an asymmetrical foil with a maximum thickness of 10 % chord (see appendix B). The section was used based on its simplistic shape and its lift and drag characteristics. Also selection of this shape was governed by its ease of fabrication. Final design of the water propeller was as follows:

Number	=	2 Blades
Blade Length	=	1 foot, 3 inches (38 cm)
Chord at Hub	=	4 inches (10 cm)
Chord at Tip	=	2 inches (5 cm)
Pitch at Hub	=	78 degrees
Pitch at Tip	=	18 degrees

Manufacturing of the propeller was done by hand. The material was wood. Six 5/8 inch (16 mm) by 4 inch (10 cm) by 2 1/2 foot (76 cm) ash boards were laminated together with epoxy. Then with the use of a hand saw, wood chisel, wood shaper, and an electric belt sander, the propeller was formed. The 3 inch (76 mm) diameter hub was drilled and a spline gear pressed into it. Finally the propeller was coated with epoxy. By noting the crudeness of the manufacturing method, it should now be apparent why the simple airfoil shape was desired.

STABILITY CONSIDERATIONS

Since the catamaran is basically very stable statically, and safety is of primary concern, a conservative estimate of only the dynamic stability is considered. The energy method [8] is employed whereby it is necessary to know the magnitude and location of the forces acting dynamically on the catamaran.

First, the weight and center of gravity of the catamaran and several crew arrangements are determined by the method of parts [1]. Second, expected maximum wind and thruster forces are estimated and located at their maximum moment arms. Then, the location of the buoyant force is determined as a function of the heel or incline angle. Finally, a net righting moment is determined for both transverse angles of heel and longitudinal angles of incline and a plot of righting moment vs. angle of heel or incline is generated.

Assumptions for the analysis include: (i) stability due to hull shape is negligible [8], (ii) moments produced by drag forces are negligible , (iii) moment arm distances are considered to be conservative [7] and chosen to simplify the analysis, and (iv) buoyant force location relationships are considered conservative and are also chosen to simplify the analysis. The location of the buoyant force is perhaps the most difficult to assess of all the forces. Tedious waterline drawings for all load cases and a range of heel or incline angles must be done. However, in the short course of sixteen weeks that this project was to be completed, a more practical, yet conservative approach was used.

The location of the transverse buoyant force is approximately at the center of the leeward hull when the windward hull just begins to lift out of the water, θ (lift). Between zero degrees and (lift) the buoyant force location moves from the centerline of the catamaran to the leeward hull, respectively.

This can be represented by the following equations:

x = k*(1- / (lift)) (conservative)

x = k*(1-SQR(/ (lift)) (more realistic)

where, x = distance from leeward hull
k = distance from leeward hull to centerline

The first equation was used for safety reasons in much the same way that safety factors are employed. However, it is interesting to note that the latter equation better fit static testing data.

A similar approach was used for the longitudinal buoyant force location but instead of (lift) there is a (max) at which there is no longer a significant change in buoyant force location. Here, x is the distance from the location of the buoyant force at (max) and k is the distance from the location of the buoyant force at (max) to the location of the buoyant force at zero incline angle.

A program has been written in APPLESOFT BASIC using the above technique and assumptions. This allows rapid analysis of various load cases to ensure safety for all conditions. Appendix C shows some example computer runs. A major effect on the design was seen when it was determined to lower the wind turbine a difference of three feet (91 cm) from the original design to ensure that all expected load cases were stable.

ACKNOWLEDGEMENTS

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Jerry Miller, lab machinist

Prof. B.L. Blackford
Dalhousie University
Halifax, Canada

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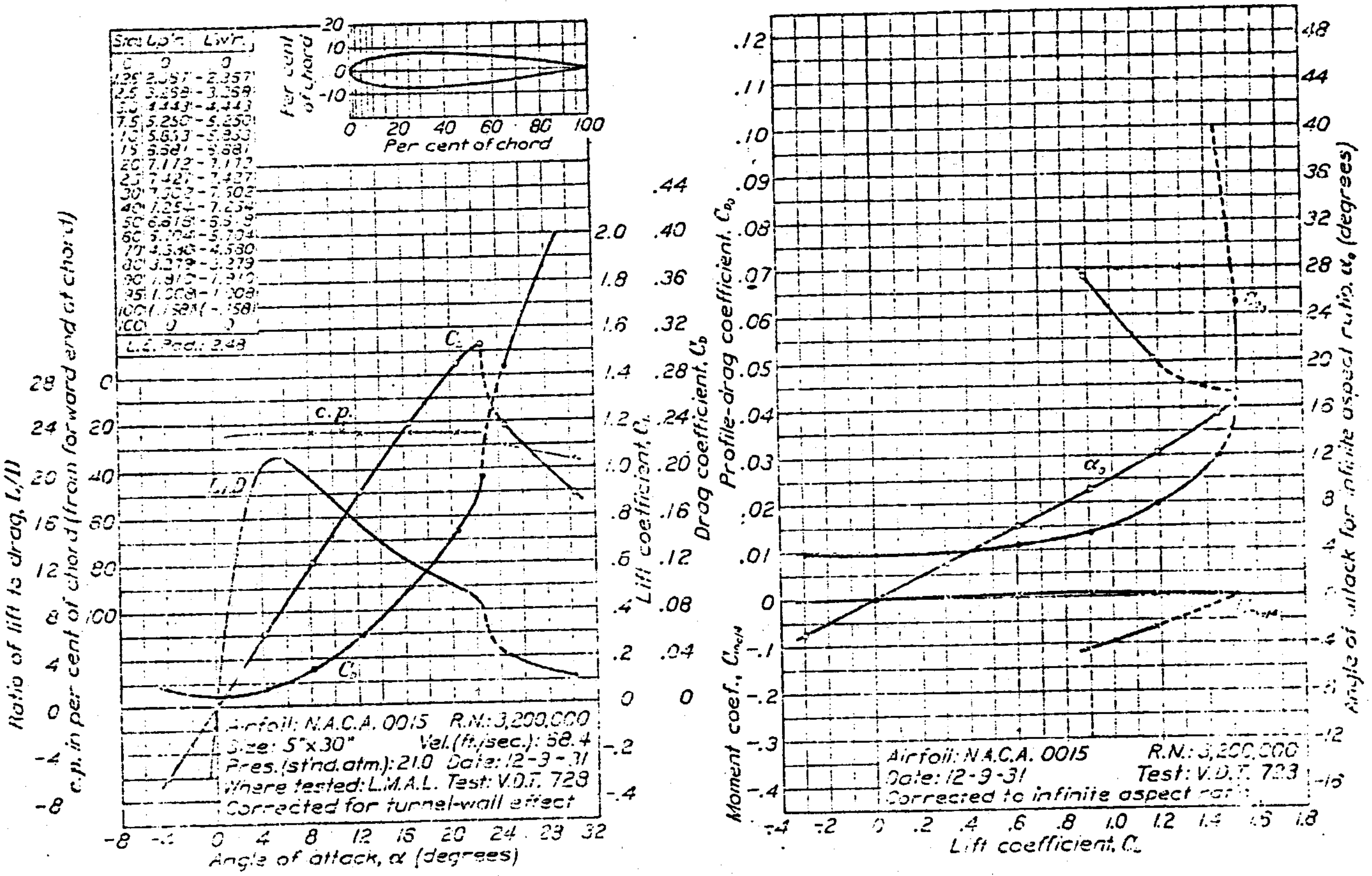
APPENDIX A

Material List

Hulls	1/8 inch (3.2 mm) Door Skin Plywood 1 inch (2.5 cm) x 1/2 inch (1.3 cm) Pine boards 1 inch (2.5 cm) Plywood 10 oz. (284 g) cloth, s-glass fiberglas Epoxy Copper wire Brass nails
Cross Members	2 inch (5.1 cm) x 4 inch (10.2 cm) Boards 1/4 inch (6.4 mm) Plywood Epoxy Brass Nails
Rudders	1/2 inch (1.3 cm) Plywood 3/4 inch (1.9 cm) Dia. Aluminum Tubing Epoxy Wood Screws
Wind Turbine	Low Density Styrofoam 10 oz. (284 g) cloth, s-glass fiberglas Uni-directional e-glass fiberglas 1 inch (2.5 cm) wide Graphite fiber strips Epoxy Aluminum Fixtures (custom built) Stainless Steel bolts Small Lead weights
Water Propeller	5/8 inch (16 mm) x 4 inch (10.2 cm) Ash boards Brass Spline Gear Epoxy
Mast	Aluminum Tubing Aluminum Fixtures (custom made) Steel Roller Bearings Various Hardware



The polynomials describing the above curves for an infinite aspect ratio are as follows:

Angle of attack versus lift coefficient -

For x less than 18:

Cl = -8. 4803193E-14*X↑9 + 1.40160219E-11*X↑8 - 2.64855492E-10*X↑7

-5.38569573E-9*X↑6 - 2.23018792E-7*X↑5 + 1.18893026E-5*X↑4

-3.48499697E-5*X↑3 + 0.00338514269*X↑2 - 0.251519198*X

+4.3348144

For x greater than 18:

```
Cl = 7.67735877E-11*X↑9 - 2.38070305E-9*X↑8 + 1.25430155E-8*X↑7
     +2.31036434E-7*X↑6 - 2.8585385E-6*X↑5 + 9.20336732E-6*X↑4
     +2.72684358E-6*X↑3 - 4.43205813E-5*X↑2 + 0.100029807*X
     +6.3523903E-6
```

Lift coefficient versus drag coefficient -

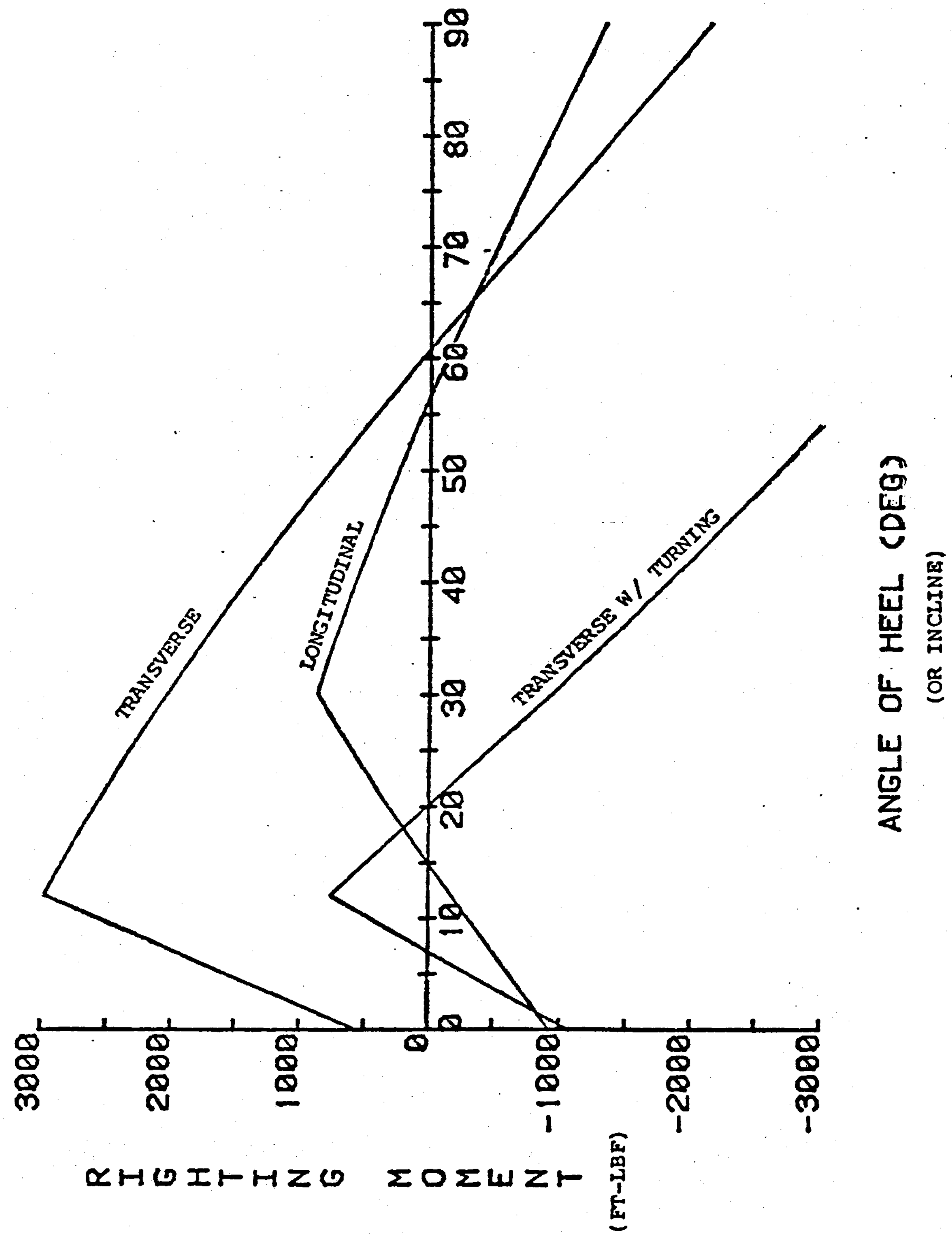
```
Cd = 0.0405785516*Cl↑9 - 0.160805865*Cl↑8 + 0.194127902*Cl↑7
     -0.00395913293*Cl↑6 - 0.148965146*Cl↑5 + 0.0948506023*Cl↑4
     -0.0103834909*Cl↑3 - 6.07669817E-5*Cl↑2 + 0.00116198723*Cl
     0.00899711821
```

Polynomial describing lift-drag characteristics of 3R10 Airfoil

```
Cl = 1.94440743E-11*X↑10 - 2.41655373E-10*X↑9 - 2.66152662E-9*X↑8
     -1.05461122E-7*X↑7 + 4.41481848E-6*X↑6 - 4.28523317E-5*X↑5
     +6.87831608E-5*X↑4 + 6.85655539E-4*X↑3 - 2.84580209E-3*X↑2
     +0.902948592*X + 0.419999391
Cd = -1.25679705E-11*Cl↑10 + 1.10401798E-10*Cl↑9 + 1.68206102E-9*Cl↑8
     +6.02331004E-8*Cl↑7 - 2.00475312E-6*Cl↑6 + 1.58280993E-5*Cl↑5
     -4.68298375E-6*Cl↑4 - 4.10404701E-4*Cl↑3 + 1.67568033E-3*Cl↑2
     +6.35040953E-4*Cl + 0.0200005445
```

Note: 3R10 Airfoil curves not shown.

APPENDIX C



TRANSVERSE
LONGITUDINAL
TRANSVERSE W/ TURNING
ANGLE OF HEEL (DEG)
(OR INCLINE)
RIGHTING MOMENT
(FT-LBF)
3000
2000
1000
0
-1000
-2000
-3000
0
10
20
30
40
50
60
70
80
90

PERFORMANCE MEASUREMENTS ABOARD A 25 FOOT SAIL ASSISTED FISHING VESSEL

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Melbourne, Florida 32901

ABSTRACT

Described are the preliminary results of a project to determine the fuel savings available to commercial fishermen by using sails in conjunction with a conventional power service. Sea trials were conducted on a sail-assisted 25' fishing vessel beginning April 20, 1983 and at the time of this report constitute four days of measurements. Although the data collected was obtained while developing the methodology for this type of study it shows definite trends. Shown are the benefits available in rpm reduction while maintaining ship speed in the sail-assisted mode, the extent of which depends on the vessel, and wind speed and direction.

INTRODUCTION

In 1818 the American steamship Savannah was built in New York, equipped with an auxiliary steam engine. She crossed the Atlantic in 29 days but used her engine for only 80 hours. Captain Moses Rogers 'didn't go for the newfangled device'. He claimed the vessel did just as well under sail, so why carry costly fuel to do what the wind did for free? To him, paying for motion at sea was absurd.

Now, almost 170 years later somewhat the same sentiment is being shared. Fuel costs have skyrocketed and while presently decelerating the price continues to increase. In contrast to Captain Rogers it is not feasible to rely solely on wind power since present day commerce requires less and less transportation time. The problem faced is to decrease fuel consumption without increasing travel time. The use of sails as an assisting mechanism to the vessel's engine(s) seems to be a very logical solution.

TEST VESSEL

The vessel selected for the project was a Fisher design Fairways Potter 25. This type of vessel is commonly used in crab and lobster pot fishing within Europe. The hull design is of North Sea Trawler type and the dimensions are as follows:

Length, overall...............25'3"
Beam......................... 9'4"
Length, water line...........21'0"
Draft........................ 3'9"
Displacement................. 4.5 tons

The power source is a 36-horsepower Volvo-Penta, model MD3B, three cylinder, four-stroke diesel.

The standard package for this vessel is displayed in figure 1 and 2. It is strictly a power vessel equipped with a 41 square foot steading sail for damping rolling motion and station keeping while working gear.

The sail assist arrangement, shown in figure 3, is a ketch rig. The main and jib are each 102 square feet and with the mizzen comprise 245 square feet of sail. The jib is of roller furling type. All sails can be trimmed from abaft the wheelhouse.

Prior to testing, the vessel was equipped with a new jib, and the bottom scraped free of fouling, including the rudder and propeller.

TRIALS

The area in which the preliminary trials were conducted is shown in figure 5. It is located on the east coast of Florida just over one mile north of the Eau Gallie causeway, approximately fifteen miles south of Cape Kennedy in the intracoastal waterway of the Indian River. This area was considered ideal for the trials since it is open to winds from all directions, has neglible tide effect, has no currents other than from local winds, and seas generally less than two feet.

Test procedure basically involved first steaming between two known points at various engine revolutions with power alone, measuring ship velocity. The runs were then repeated with power plus sails at engine revolutions corresponding to those in the power alone runs. The preliminary data was obtained in winds from basically two directions to vessel heading, both close to a broad reach. Eventually it is planned that data will be collected to show the effects of the wind from a 360° range so including both favorable, and unfavorable directions, in light, moderate, and heavy wind conditions. It will then be possible to present a complete package of results showing benefits or detractions to using sail assist in all wind conditions and directions the vessel might encounter. Some of these factors will be discussed later.

Several approaches were tried while developing the testing methodology and the most satisfactory method to obtain the needed data is outlined here.

A triangular course was set up, utilizing two channel markers and a large orange buoy anchored in a known location. Each leg of the course was greater than one-half a nautical mile to provide ample travel distance for the runs. The triangular course shape was designed to measure up to six different wind directions by going around the course in both directions; see figure 4. Each side of the triangular course constituted a run.

Local charts were used to identify channel marker and buoy locations. This was accomplished by taking horizontal sextant angles from the markers or buoy to known landmarks. A minimum of six bearings were taken to determine each location. With this data and simple triangulation the locations were indicated on the charts and distances determined.

Figure 1.

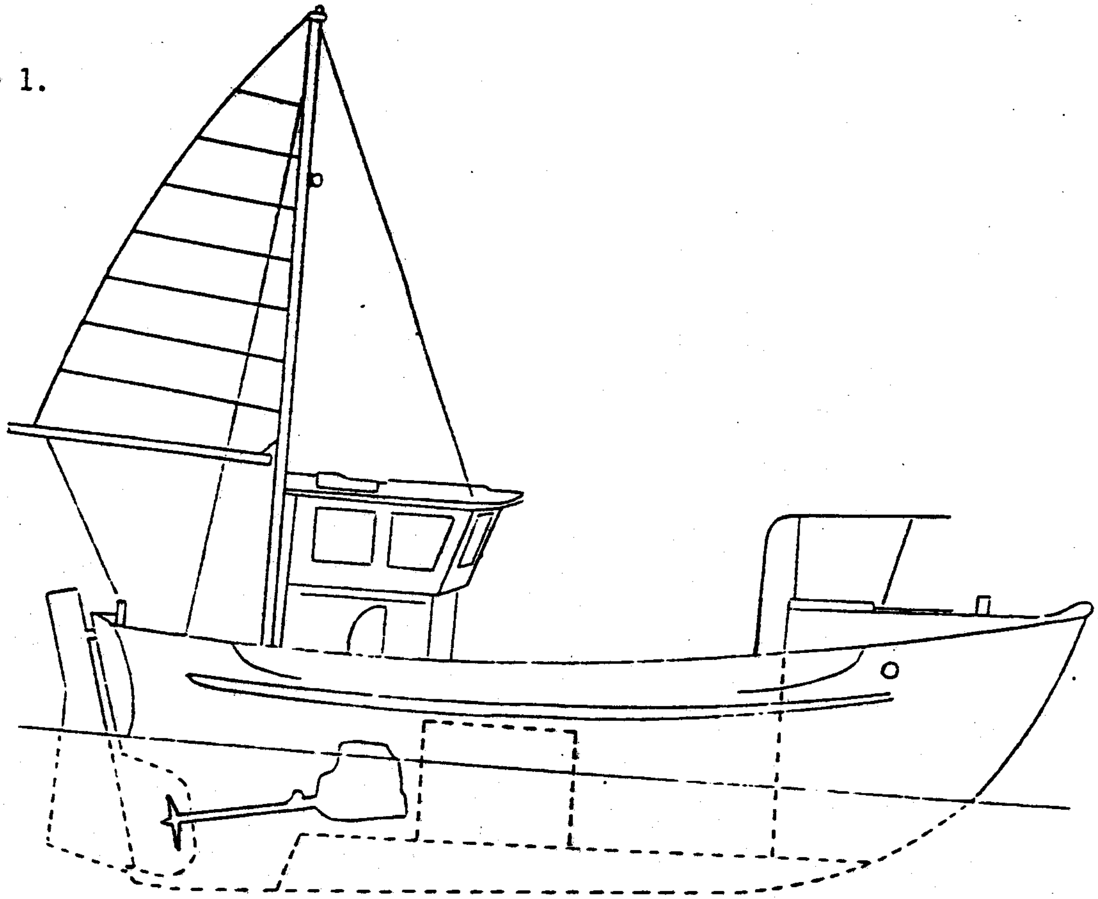
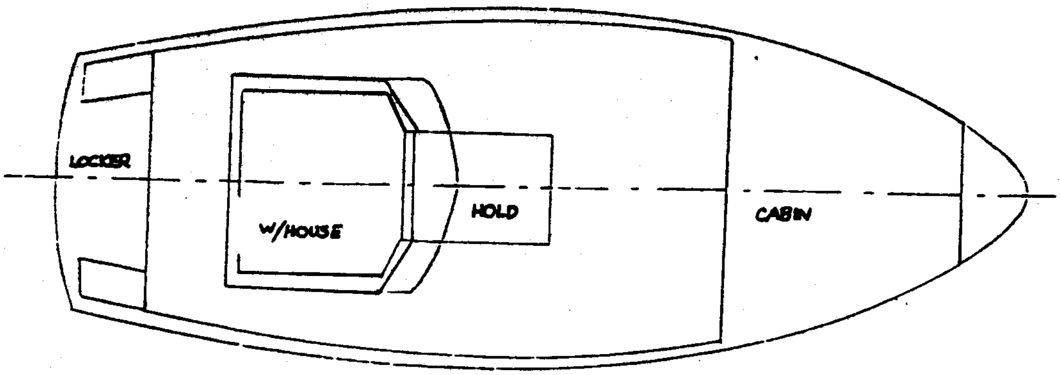


Figure 2.



Fisher Design Fairways Potter 25, North Sea Trawler hull, LDA-25'3", Beam 9'4", Draft 3'9", Displacement 4.5 tons; Standard package equipped with 41 sq. ft. steadying sail. Power source is a Volvo Penta, 36 hp, model MD3B, 3 cylinder, 4-stroke diesel.

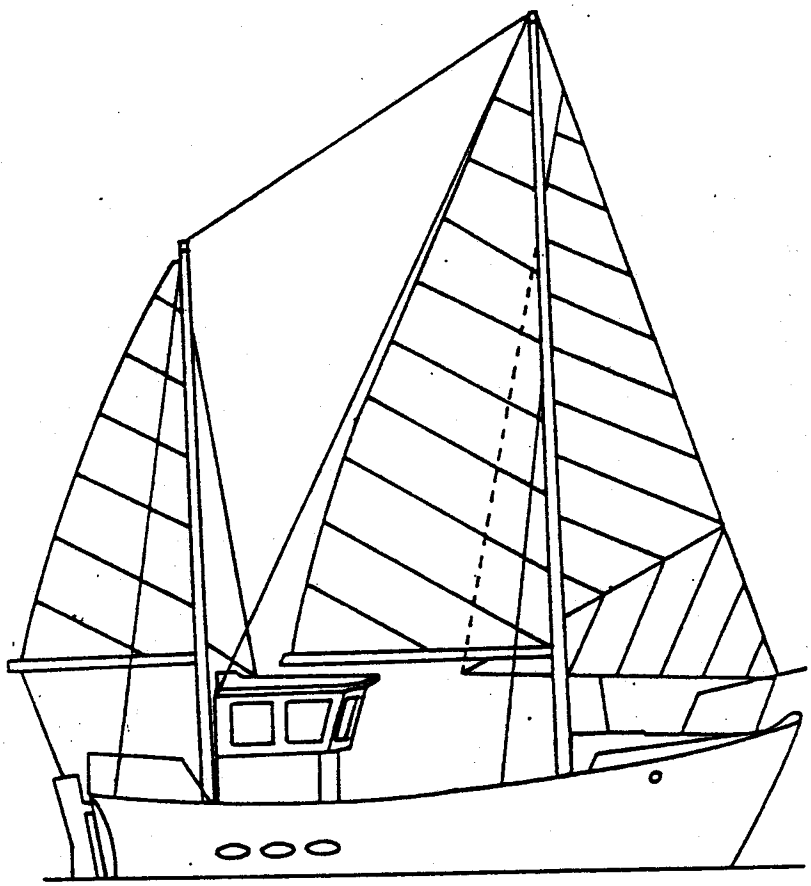


Figure 3. Sail-Assist Arrangement, Ketch rigged, with 245 sq. ft. of sail

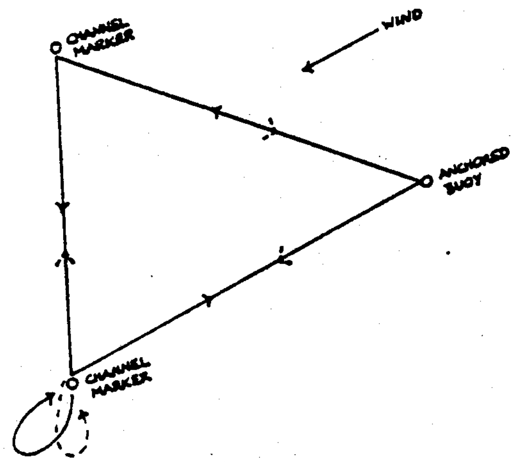


Figure 4. Course layout showing six possible wind directions to vessel headings. Each leg approximately 0.65 nm.

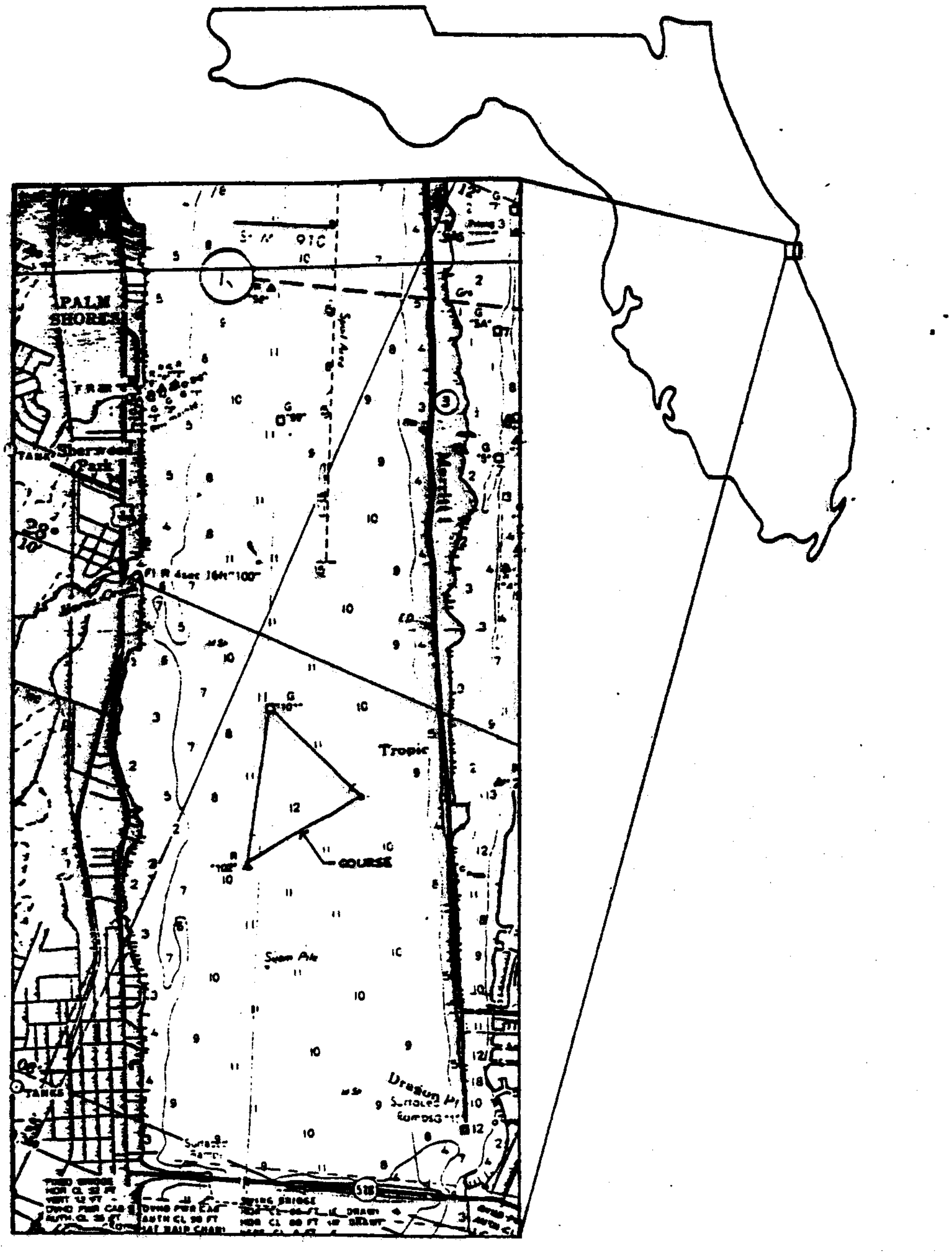


Figure 5. Trials were conducted approximately 15 miles south of Cape Kennedy on Florida's East coast in the intracoastal waters of the Indian River. The course is just over a mile north of the Eau Gallie causeway. The location proved to be ideal.

Support equipment for the trials included a 28' cruiser anchored just outside the course lanes. Onboard a battery operated anenometer measured the wind direction and speed, which was recorded every 30 seconds. An outboard powered runabout was used for buoy pickup and its crew was responsible for the sextant readings. During initial runs, an additional buoy measured to determine the distance blown off course (leeway). The headings between markers were known and the vessel would maintain these headings during a run. At the completion of each run a buoy was dropped and the distance between the marker and the buoy measured. From this distance the leeway was computed. In all cases the leeway was never greater than 2°, even when close-hauled. It must be noted that the wind was light during the runs made to date; in heavier wind conditions leeway could well prove an important parameter.

At the beginning of each run the support vessels were notified and a timer started when passing the starting mark. The course bearing was set as determined from the charts and held throughout the run. Recorded onboard the test vessel was the trial number, propulsion mode, starting/stopping points, rpm's, vessel bearing, knotstick speed, run time, heel, and apparent wind. Vessel speed was calculated by dividing the known distance of the trial leg by the run time. The knotstick was intended to be used as a check but proved to be inaccurate so that its use was discontinued.

At the end of each run the time was recorded, the leeway buoy dropped, and preparations made for the next run. The vessel's course was always established some distance before the starting mark to insure a steady speed at the start of each run. Prior to passing the starting mark the runabout returned the leeway buoy.

Runs were made with power alone at rpms from 800 to 1900 and then duplicated with all sails up and set by experience.

From the initial trials enough data to produce preliminary results was obtained from winds in only two directions. The test procedure however proved satisfactory and more trials will be performed in the future. Each recorded run was duplicated to insure accuracy.

RESULTS

The preliminary results are shown in the graphs in figures 6-8 and also in the beginnings of polar curves in figures 9-11. All the data collected thus far points to a definite advantage in using sails along with power in favorable winds. The graphs presented indicate the extent of the advantages, especially at speeds where $V/\sqrt{L} \approx 1.1-1.2$, the cruising speed of many commercial fishing vessels. From the graphs it is a simple matter to determine the reduction in rpm's made possible with the sail-assist mode while still maintaining ship speed.

The majority of data collected so far has been in relatively light winds. It is anticipated the advantages of using sails as auxilary power will be even more apparent in heavier winds, so long as the direction is favorable. With the procedure now proven, additional data will be collected and classified according to wind direction in the more

Figure 6. Engine revolutions versus ship speed. Vessel heading was 347°, magnetic.

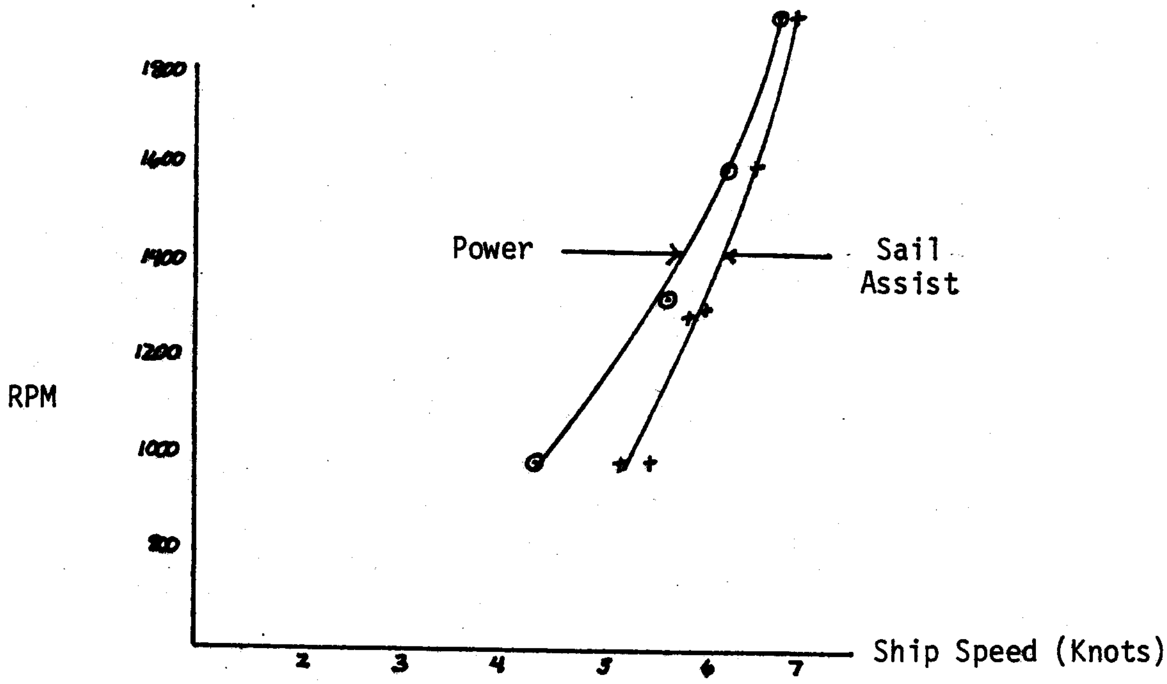


TABLE 1

	RPM	VEL.	WIND DIR.	WIND TO COURSE	WIND SPEED
Power	1000	4.25	---	---	---
	1330	5.68	---	---	---
	1600	6.17	---	---	---
	1900	6.58	---	---	---
Sail Assist	1000	5.09	71.8°	84.8°	5.0
	1000	5.32	113.1°	126.1°	6.55
	1300	5.78	89.4°	102.4°	4.28
	1310	5.92	63.4°	76.4°	6.25
	1600	6.35	62.8°	75.8°	4.86
	1900	6.73	66.2°	79.2°	3.92

Figure 7. Engine revolutions versus ship speed. Vessel heading was 167°, magnetic.

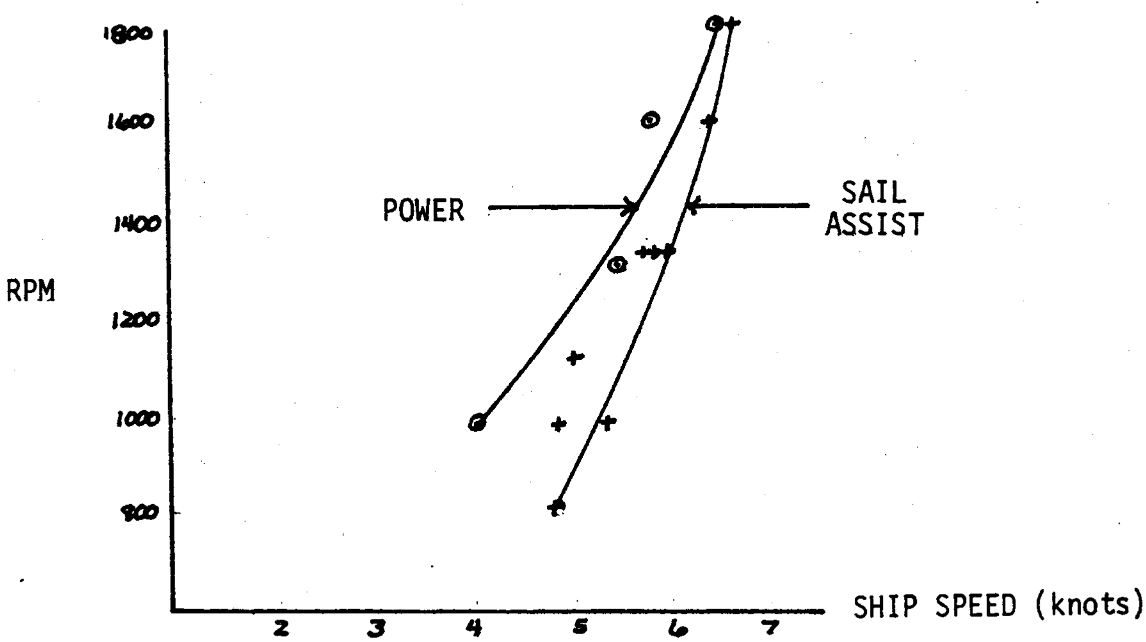


TABLE 2

RPM	VEL.	WIND DIR.	wind to course	WIND SPEED
1000	4.10	---	---	---
1300	5.68	---	---	---
1600	5.79	---	---	---
1910	6.40	---	---	---
800	4.84	84.2°	82.8°	6.77
1000	4.79	62.3°	104.2°	4.93
1000	5.29	85.6°	81.4°	8.11
1150	4.97	113.1°	53.9°	5.77
1300	5.50	62.7°	104.3°	5.35
1300	5.58	86.2°	80.8°	5.28
1300	5.63	79.4°	87.6°	5.55
1600	5.90	61.2°	105.7°	4.23
1900	6.33	72.4°	94.6°	4.41

Figure 8. Wind effects with power alone. The vessel's direction to the wind is indicated. Wind speed was 15-20 knots.

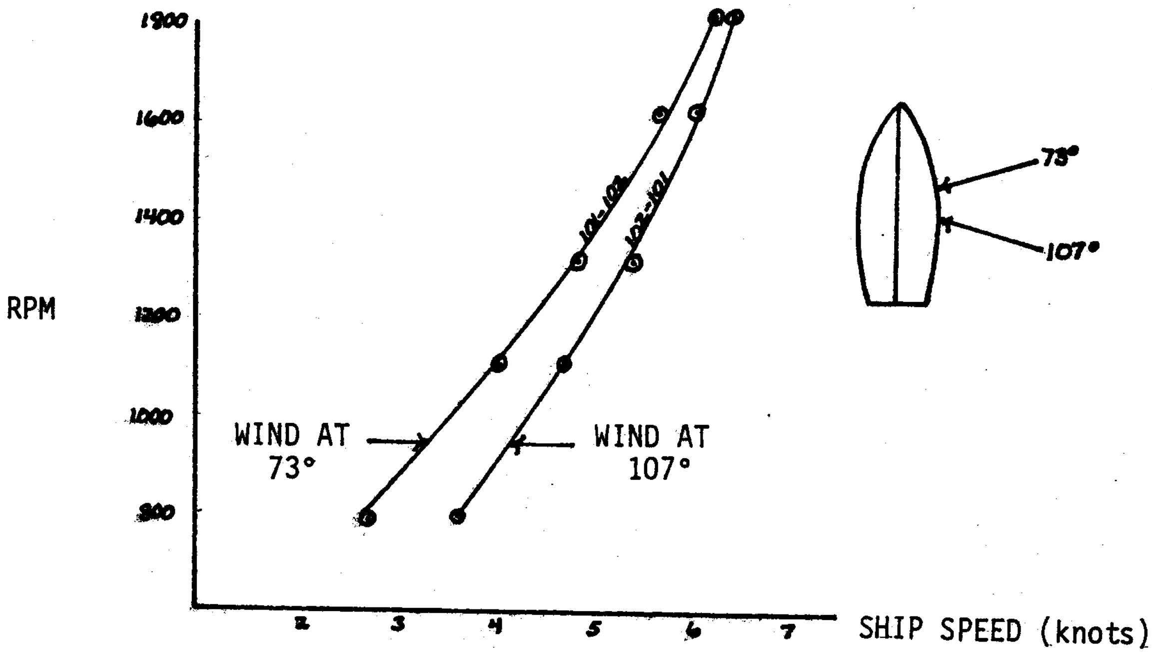


TABLE 3

	SHIP SPEED (knots)	
RPM	101-102	102-101
800	2.78	3.61
1100	4.09	4.70
1300	5.02	5.23
1600	5.76	5.83
1800	6.13	6.16

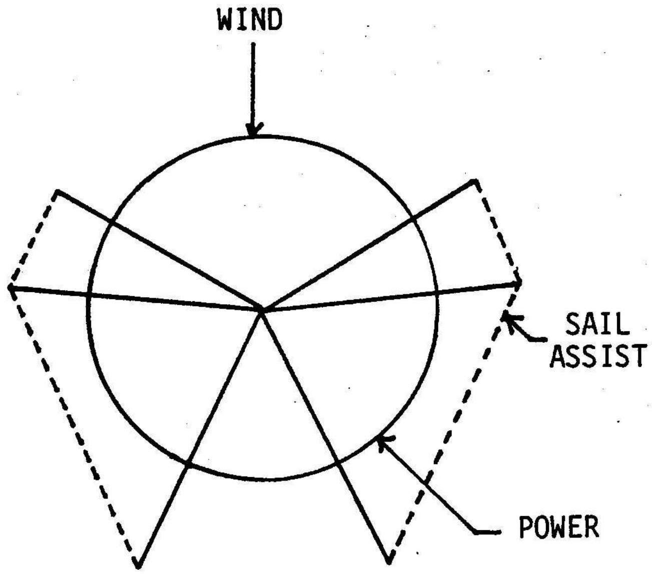


Figure 9. RPM = 800
Power Alone (Ave.) = 3.19 knots
Wind Velocity = 6.77-9.80 knots

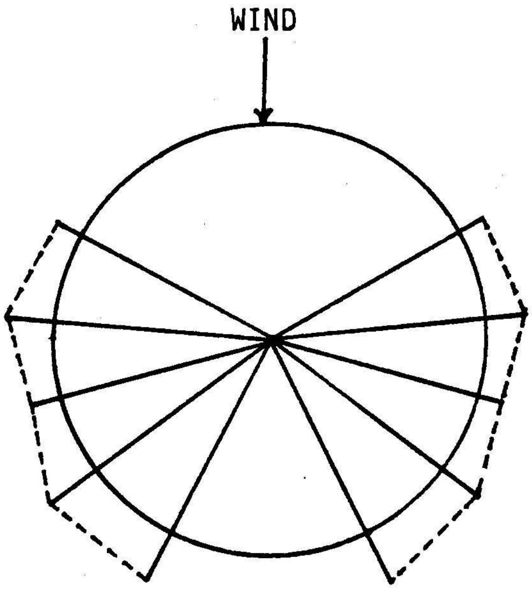


Figure 10. RPM = 1000
Power Alone (Ave.) = 4.2 knots
Wind Velocity = 5.0-7.0 knots

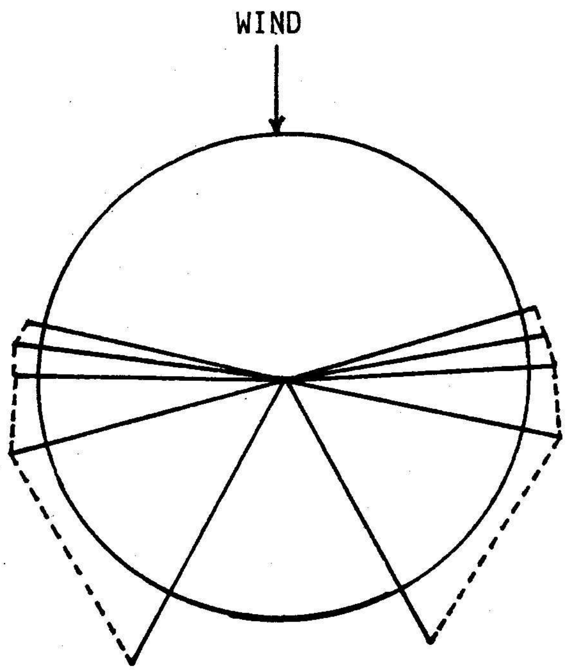


Figure 11. RPM = 1300
Power Alone (Ave.) = 5.1 knots
Wind Velocity = 4.3-6.2 knots

classical terms of whether the vessel is running, reaching, or close-hauled. The degrees of each will be noted. The percentage of rpm reduction made available by sails decreases in the higher rpm ranges as hull speed is approached.

In most cases rpm reduction coincides with decreased fuel consumption so that from initial trials it is apparent that substantial fuel savings may be possible.

The graph shown in figure 8 was produced from data collected using the vessel's power alone, without sail assist. Due to storm conditions the sail runs were postponed. This graph does show the effect wind direction can have on a vessels' fuel efficiency due to resistance created by wind on the above water structure. The winds were moderate during the trials. The extent of the wind resistance from all directions will be further explored as testing continues.

A pictorial representation of the speeds recorded in both the power alone and sail assist modes at a constant rpm are shown in figures 9-11. The solid power alone circle at the present represents the magnitude of the average speed obtained in all directions. As more data is collected it is expected the downwind point on the circle will elongate due to increased speed because of the winds pushing effect and the circle will take on more of an egg shape. This is due to wind created resistance on the above water structure, emphasized in figure 8. This will reduce the represented advantage of sails when the vessel is running.

The dotted lines representing sail assist speeds only connect the points plotted from the data collected to date and do not necessarily represent the expected speed at a particular unplotted wind direction. Due to lack of data it would be presumptuous at this point to produce the expected curve. When completed, these figures will be the standard polar curves.

At 800 rpms, just above idling speed, the added speed from sails is most dramatically represented. The advantage, naturally, decreases as the vessel points into the wind. Unduplicated runs have shown the expected disadvantage of using sails when heading into the wind. The resulting speed in this case was always less than with power alone. As the rpms are increased the additional speed from the sails decreases percentage-wise.

It must be noted again these results were obtained from light air trials. Heavier winds are expected to show even more efficency can be gained with sail assist.

CONCLUSION

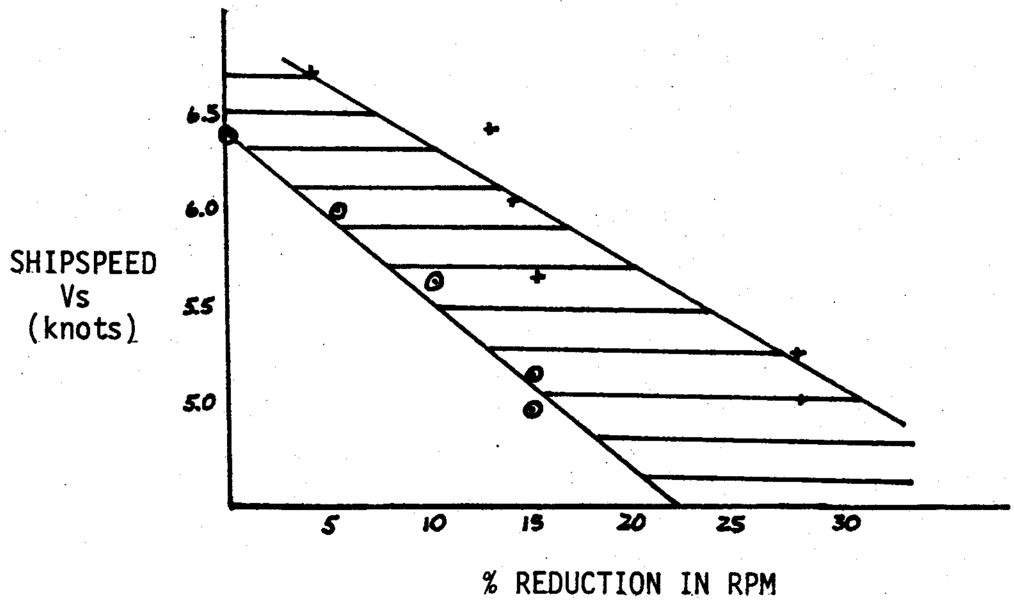
The preliminary data analyzed to date shows that with favorable wind conditions and by assisting the main power plant with sails it is possible to markedly reduce the engines' rpms (28%) and still maintain the vessles cruising speed. The advantage was reduced as hull speed was approached (5%). The conclusions are shown in Table 4 and represented in figure 12.

TABLE 4

Vs (knots)	RPM's		REDUCTION IN RPM'S WITH SAIL ASSIST	% RPM REDUCTION
	POWER	* SAIL ASSIST		
5.0	1200-50	880-1000	200-370	16-29
5.3	1300-90	1000-1100	200-390	15-28
5.6	1400-1500	1250	150-250	11-17
6.0	1550-1650	1400-50	100-250	4.5-15
6.3	1700-1825	1550-1700	0-275	0-15
6.6	1900	1800	100	5

* RPM'S REQUIRED ARE A FUNCTION OF TACK

Figure 12. Reduction in rpm to maintain shipspeed..



The winds during the trial were light but in a favorable direction for the vessel during the trials, mostly on the beam. As the study continues, additional less favorable wind direction data will be accumulated and the resulting performances explored, as well as different wind intensities. As the propeller characteristics are known, it should be possible to convert RPM reductions into power reductions and thereby allow initial range estimates of fuel savings.

ACKNOWLEDGEMENT

This project is sponsored by Florida Institute of Technology.

The authors' wish to thank associated Marine Sections of Melbourne, Florida for the use of their fishing vessel, ISLANDER. Thanks are also due to Dave Hill, Dave DuPont, Steve Thayer, Jim McIntyre, Steve Fluhr, and Capt. Jack Morton for assisting in data collection.

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REVIEW: SAIL-ASSISTED FISHING VESSELS FOR GULF OF MEXICO, CARIBBEAN AND NEAR-ATLANTIC WATERS
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Reviewer: Clifford A. Goudey, NA
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The author presents a review of a series of related studies by the University of South Florida on sail-assist applied to fishing vessels of the southeastern United States. Three types of existing craft are considred for retrofit installations; snapper/grouper boats, stone crab/lobster boats, and shrimp trawlers. The author reports positive, negative, and somewhat positive results for each type, respectively.

These results appear realistic however, some of the criteria for sail-assist power established by the author deserve further consideration. Mr. Shortall postulates that a year-round fuel savings of at least 15% should be anticipated before retrofit sails are installed. This criteria pays no regard to the installation cost or the significance of fuel expenses in the vessel's present budget. A simple payback criteria would be more appropriate.

The simplicity of unstayed masts makes them attractive from a design and an operational point of view. In retrofit cases, however, significant internal hull and deck reinforcing would be necessary to support such a concentrated load. In addition, in most fisheries, masts are used for hoisting during the handling of the fishing gear and for dockside loading. The conventional stayed mast seems more appropriate for these tasks and their present popularity weakens any argument that they interfere with fishing operations.

The author's requirement that a rig be close-winded deserves reconsideration. Present fishing vessel hull forms preclude such performance. Their typical entrance angle, beam and bow flare cause extraordinary added resistance in head seas.[1] They would wallow when close hauled. Any incremental thrust while motor sailing close hauled would, of course, be welcomed but the major benefit would be roll damping. Retrofit sail plans for reaching and downwind sailing must be considered valid possibilities.

The paper includes some interesting statistics on wind patterns in the Florida area and describes useful techniques for including these factors in the overall economic analysis. The conclusions that Gulf/Caribbean wind conditions are favorable for fishing vessel sail-assist bids well for other parts of the country since Wind Ships' study[2] rated that region low for wind-assisted cargo ships, compared to other U.S. trade routes.

The conceptual sketches presented for the snapper/grouper and lobster boats seem reasonable based on the criteria used. The economic results also seem acceptable though they can no doubt be improved upon through application of some of the analysis techniques presented at this conference. It would be interesting to know if economic analyses were done on sail plans smaller than the maximum allowed by the author's stability criteria.

Also presented are conceptual designs for a series of sail-assisted catamaran fishing vessels. These designs are intriguing but lack the detail on auxiliary powering, sail performance, and survivability to judge fairly. The author's conclusion that they offer cost advantages may be premature and is not evident from the material presented.

The strong conclusions on the merit of present fishing boat designs are too harsh. Their inefficient hull forms are a product of fishermen's attitudes and today's economics, not the fault of their designers and builders. Fishermen, like all businessmen, are interested in the bottom line -- profits. The stubby, hard-chined vessels of today give him fishing capability at a minimum initial cost. In addition, deck layouts and gear handling techniques have developed hand-in-hand with these designs and revolutionary changes will come with difficulty, if at all. We must insert our sail-assist insight carefully and methodically into the present scheme.

Mr. Shortall is to be congratulated on an interesting and useful paper. It represents the results of an obviously well-directed program of study which he has spearheaded.

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WIND PROPULSION DESIGN FOR NORTH ATLANTIC

K.C. Morisseau
Naval Sea Systems Command
Washington, D.C. 20362

DATA SOURCE: Annual Sea State Occurances in the North Atlantic - DTNSRDC

	S/S	Range/Mean Wind Speed* (Knots)		% Probability	Com	
	(0-2)	(0-10)	(8)	(72)	7.2	
	3	11-16/	13.5	22.4	29.6	
MEAN-	4	17-21/	19	.28.4	58.3	MEAN
	5	22-27/	24.5	.15.5	73.8	
	6	28-47/	37.5	18.7	92.5	
	(>6)	(48-63)/	(53)	(7.4)	99.9	
				85.3		
				(14.6)		
				99.9		

*19.5 M or 63 ft above surface - For 10 M or 32.5 ft reduce valves by 20%.

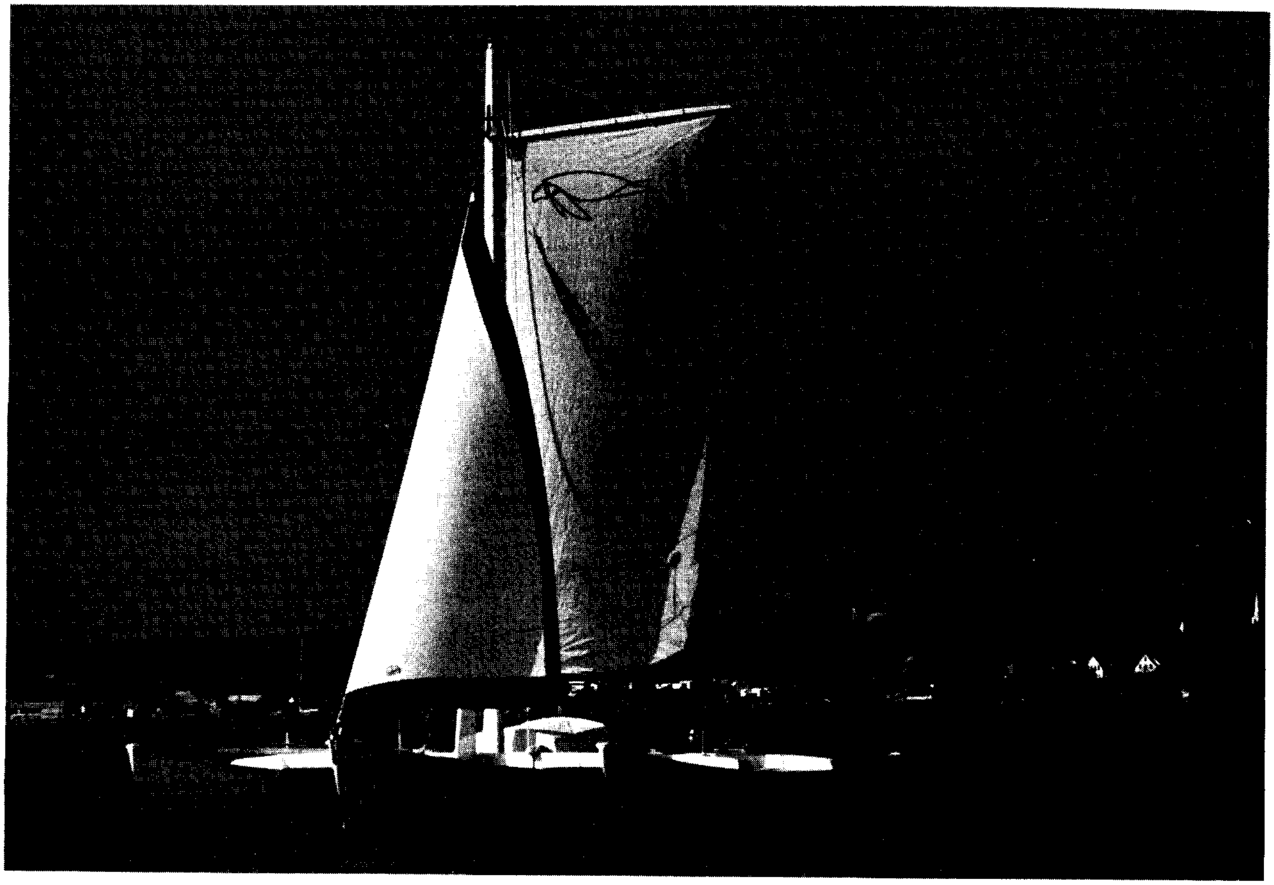
Possible Conclusions for Wind Propuslion Systems for use in N. Atlantic

- Design for wind speeds in the 1-10 & 48 & higher knot speed ranges is not worthwhile as use would be less than 15% and cost would be out of line w/return.

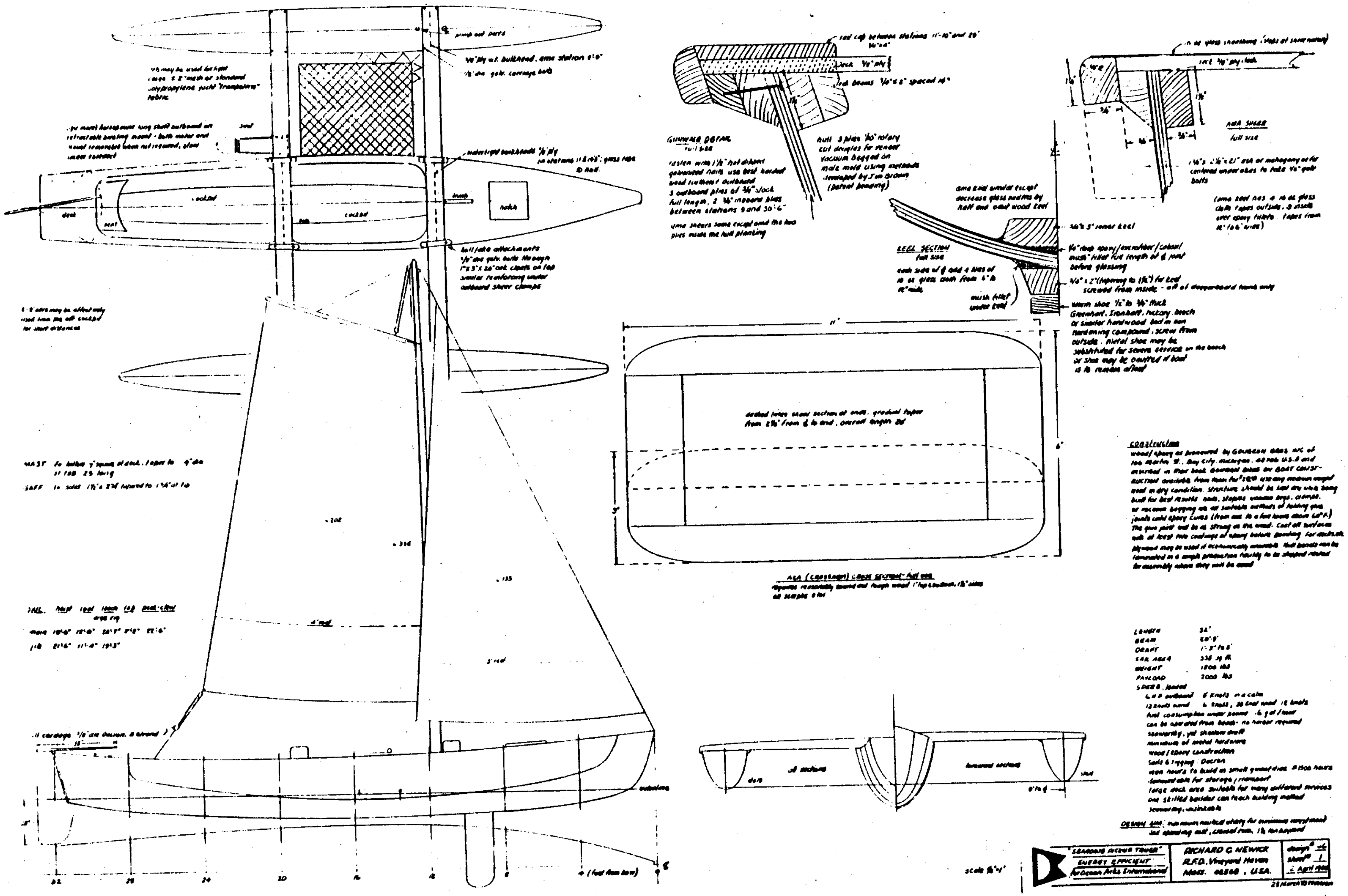
- Optimum design point is 22 to 23 knots.

SEABORNE PICKUP TRUCK FOR OCEAN ARKS INTERNATIONAL

Richard G. Newick
High Performance Boats
RFD Box 309
Vineyardhaven, MA 02568 USA



32 foot, 1.5 ton Ocean Pickup EDITH MUMA, from Ocean Arks International, leaving Martha's Vineyard for Guyana, May, 1983.


construction
LENGTH 32'
BEAM 20'9"
DRAFT 1'-3" to 5'
SAIL AREA 336 sq ft
WEIGHT 1800 lbs
PAYLOAD 2000 lbs
SPEED, loaded
6 knots in a calm
sails & rigging: Dacron
wood / epoxy construction
minimum of metal hardware
seaworthy, unsinkable
KEEL SECTION
full size
GUNWALE DETAIL
AKA SHEER
full size
scale 3/8"=1'
"SEAGOING PICKUP TRUCK"
ENERGY EFFICIENT
for Ocean Arks International
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SIMPLIFIED SAIL HANDLING FOR YACHTS AND COMMERCIAL VESSELS

by

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MACHINES TO HELP SAILING

There are many instances on a sailboat when one would like to make a sail change, but the job is too much for one man, because many hands and great strength are required. At such a time, every mechanical advantage available is highly welcome. A modern geared winch will permit today's sailor to perform far more effectively than was possible 100 years ago. A good powered winch will permit him to do today what could not have been done 30 years ago.

In the past ten years, the market for such devices has grown substantially for yachts and one can safely predict that the demand for power winches and power furlures will greatly increase in the future, for both yachts and commercial vessels.

MECHANIZED VERSUS AUTOMATED SAIL HANDLING

In an attempt to de-skill sailing there are two degrees of simplification possible. If one wants to automate sailing vessels electronically, they must first have a sound means of mechanizing sail handling.

Let us define our terms at the outset:

A completely automated commercial sailing vessel would need no human input whatsoever. Sails would be trimmed automatically, as well as reefed automatically depending on wind direction and force. The Japanese are reported to have gone further in this direction than any other nation.

A vessel that has its sail handling functions mechanized, would require humans to press buttons and turn dials to set, trim, reef, and furl its sails. It would require few people and no brawn. Thus, step one is to mechanize with machinery, and step two is to electronically control the machinery. It is in the

Delivered at 1982 Westlawn Yacht Design Symposium - January 1982.

first step, the mechanization of sailhandling, in which I have become progressively more involved in the past 12 years. Originally and primarily it was in an effort to simplify sailhandling on yachts that I became involved. I am convinced that much of what is learned on yachts is directly applicable to commercial vessels if scaled up enough.

Two examples of how far it is possible to mechanize sailhandling can be seen on two boats of my design, the 86-foot cutter Aria II and the 62-foot cutter Falcon II. Both boats are boomless, Aria II having three electro-mechanically rotating luffs, while Falcon II has four rotating stays. This means that any sail can be unfurled, or reefed by activating one button and trimming or easing one line, from one position, by one person.

To my knowledge, they are the most mechanized and simplified sailhandlers in the world today, for they have no booms, no outhauls, no topping lifts, no boom vangs, no fore guys and no deck travellers. In a 25 knot wind, their mainsails can, without doing any damage, be jibed all standing ten times (or more) in a row without anyone touching a line or button or previously flattening the mainsail.

These two craft have had a combined ten seasons of sailing with extremely high reliability and many sailsets with a maximum of speed and absolute minimum of human effort.

What, one may well ask, is the next step to complete the mechanization of sail handling. It is very simply (or fairly simply) to provide a sheet winch which is both self-tailing and self-easing. Numerous such drum and reel winches are in commercial use in the fishing fleet, on offshore oil equipment, on ocean towboats, and in many other marine applications.

AUTOMATING

Since the mechanics are understood and properly practiced by a few, it simply remains to electronically control the machines by primarily interfacing existing devices that sense wind direction, and force, as well as compass course. Secondarily sensing sheet tension, heel angle and ship's speed would further assist the "sailing program" in a micro-computer. With increased sophistication satellite navigation, loran and other navigational devices can contribute to theelectronic control of sails to automate as much as may be desired. The propeller pitch, the amount and trim of sail, and the amount of main engine power from zero to full power can be controlled automatically, electronically.

Manual overriding would of course be possible, but can be expected to become less and less necessary as years go by and the automated sailing ships become more sophisticated and reliable.

From a yachtsman's standpoint, mechanizing sail handling is probably sufficient, for it certainly is of great assistance in reducing the necessity for large crews. On Aria II, seven seasons ago, when she was new, I was pleasantly surprised to see how much fun it is for one person to trim a 2,800 square foot genoa or a 3,600 square foot drifter faster with an electric winch than could be done by four strong men manually. It gives one a sense of power and control over the elements that one would not have if one had to call for assistance from three or four shipmates to perform the same task.

It is the writer's opinion that the fastest way to implement the utilization of commercial sail to reduce fuel consumption, is the scaling up of the very best already in use, mechanized sail handling equipment found on some yachts. Scaling up to larger sizes is always best done in modest steps rather than huge leaps. Scaling up existing successful sailing mechanisms would be fine in my opinion, if taken in steps of 50% or 100% at a time. On the other hand, I think it would be unfortunate and a definite mistake to try to jump 300% or 500% in one step without having had intermediate experience.

The scaling up steps being taken by the Japanese government and Japanese industry seem very sound and constitute an excellent example that the rest of the world might well follow.

TYPE OF RIG AND SAILPAN

On the other hand, I think it is unfortunate that the Japanese have elected to proceed with the square rig rather than the fore-and-aft rig in their development of commercial sail. A great deal has been learned about airfoil lift theory in the last 80 years and it seems very unfortunate to try to operate with an airfoil that has to operate equally well "forwards and backwards", that is to say with the air flowing across the foil from luff to leech on one tack, and the opposite way on the other tack. Such a dual direction of flow dooms the airfoil shape to a low efficiency. The camber distribution is wrong and the trailing edge is too thick. The mast on the windward side of the sail disturbs the flow on that side and further down-grades "lift" efficiency.

Triangular, luffroller-furling sails have proven themselves to be the fastest, easiest, most reliable, and most effective way to present sail area to the wind in order to harness it. The airfoil shape that a soft triangular sail assumes the proper warp on each tack. In commercial applications, it may be well to avoid the reefing mode since luff roller furling sails that do not need to operate in the reefed condition can be built for about 15% less cost, than ones that are to withstand the chafe built luff roller reefing creates. Thus on a large commercial vessel I would propose to have multiple masts and sails, so that reducing sail could be done in increments created by putting away one whole sail at a time. Hence a seven-sailed, three-masted vessel could roll up one sail, thus effecting a one-seventh reduction on furling the first sail, a one-sixth reduction on furling the second sail, a one-fifth reduction the third, and so on. Obviously the first sails to go would be the largest, lightest weather sails and the last would be the smallest, strongest heavy weather sails.

A yacht, on the other hand, that might only have two or three luff roller furling sails could not do this and would require that at least two of its sails be able to be roller <u>reefed</u> to any percent from zero to one hundred percent and still have an efficient shape and also be strong enough and chafe protected.

<u>WING SAILS</u>

By a wing-sail we mean a sail that is built like an airplane wing, and that is stood on end.

To suggest that in this century we could use wing sails that are neither furling nor reefing and can only be feathered into the wind in storm conditions does not seem to be an at all practical suggestion. This arrangement might work satisfactorily in winds up to 40, or even 50 miles an hour, but above 50 mph, when one gets into the 70 mph, 80 mph, 90 mph, and higher wind ranges, it would seem suicidal to try to keep large wing sails up. In harbor, such large wing sails could cause devastating damage even if allowed to feather into the strong gusts of wind that would inevitably eventually occur.

The very fact that no yacht designers have been able to create a wing sail that can be left up overnight or that can sail trans-oceanic would indicate that such devices are possibly not for this century with our present know-how. Thus developers of commercial sail might be well advised to stay clear of the wingsail concept even though some of the lift coefficients and the aerodynamic beauty of the system might seem enticing. That is not to say that one could not create a metal structure on which a flexible sail cloth material might be stretched to from a wingsail. The difference being that such an arrangement would permit one to remove the sail area in storm conditions. Such devices would seem to be inevitably cumbersome and troublesome.

One of the greatest fallacies of the wing sail is that it completely ignores the wind gradient phenomena. Since the force of the wind increases the higher one goes above the ocean surface, the vector resultant of ship's speed and wind speed will become larger and "freer" the higher one goes. Airplane wings basically operate at one altitude at a time whereas a vertical wing would have different elements at different altitudes at all times. The differential wind speed caused by the gradient, means that the sail, or in this case the wingsail, should be warped accordingly, so that the bottom is trimmed flatter and the upper part is trimmed freer, and the warp is continuous, gradual and aerodynamically correct.

The shorter the mast and the faster the boat, the more one can overlook the wind gradient as in iceboats and racing catamarans. In relatively slow merchant vessels with relatively tall masts it would be a fairly serious mistake to build a non-warping wing-sail.

It is because of the wind gradient that on certain occasions square riggers would operate with their lower courses aback while their upper sails were full and it became necessary to brail up and furl the lower courses. Thus with the wind freer aloft, top-gallants would be full and drawing and a man on deck facing forward could feel the wind coming straight in his face from forward. So, with all the faults of the solid wing sail we add the fact that it needs to be warped one way on one tack and warped the other way on the other tack, and the mechanical problems become so enormous that it must be thrown out in our own lifetime. If the wingsail is of fixed shape its upper part will almost always be undertrimed and only a fraction of the sail will be at optimum trim.

CONCLUSION: Soft sails are better!

DIRECTION OF PROFITABLE R & D

Inexperienced designers, lacking time at sea on large saiing vessels, sometimes make the mistake of spending too much time in vainly trying to optimize lift-drag ratios, when they should be spending much more time designing fail-safe practical rigs that permit easy sail handling.

CANTILEVERS

A freestanding mast, also call a cantilever mast, or unstayed mast, has the obvious and very great advantage that it has no shrouds to interfere with cargo handling gear. On the negative side of the ledger a cantilever mast requires a large section at the partners, and immediately below and above the partners. This large diameter greatly detracts from the efficiency of a single luffed soft sail. If one wants to up-grade this efficiency about the only way to do so is to make a double luffed sail and this immediately introduces a lot of negatives, including complexity of halyard arrangement, increased cost of sail, and double the luff support hardware on the mast. There are the further negative points of greatly increased structural strength, structural weight and the cost of reinforcing the deck at the partners. Most cantilever masts would profit considerably aerodynamically if the mast were made rotable, but this adds considerably to initial cost.

The comparative weight of the stayed mast versus the non-stayed mast, is not yet clearly agreed upon by different proponents, engineers and naval architects. From the point of view of stability, minimizing the weight aloft is of importance and from the point of view of economics, minimizing all structural weight is also important.

Comparing the weight and strength of a stayed column mast versus an unstayed cantilever mast, one must bear in mind the fatigue of materials involved. The cantilever mast is subject to fairly severe whipping during pitching which creates a fairly large tensile stress on the afterside of the mast above the partners and an equally large compression stress at the forward side of the mast. Since fatigue is a function of the number of cycles applied as well as the magnitude of stress generated by each pulse, we must concern ourselves with the number of hours that the vessel goes to windward. Transverse fatigue is due mostly to rolling, and probably occurs mostly at anchor or under power when there is no wind and no sail set. Transverse cycles are far more numerous but the force is far less severe than the pitching moments and stresses. One can intuitively realize that the rolling inertia is more of a sine function whereas the pitching inertia is more violent and whiplike and creates a curve with a rather sharp spike or cusp in the "g" vs. time curve, or the stress vs. time curve, as the bow is violently decelerated from its downward pitching plunge by the water. Thus, to summarize we can say that rolling cycles are numerous and mild and pitching cycles are severe and less frequent. The whipping of the top of a cantilever mast has a relatively large amplitude and tends to fatigue the sailcloth, sheets, and sheet hardware. It would be difficult to forecast what percent of future commercial rigs will be free standing and what percent will be stayed, but there is no doubt room for both. I can even visualize the possibility of using both on the same vessel. As an example a craft could have its forward mast or masts stayed and its aftermost sails cantilevered in order to leave the stern free of backstays and shrouds, in order to work fishing or towing gear.

A VERSATILE SAIL PLAN

One advantage of a stayed mast is that one can set two or three sails from one mast thus having a flexible sail plan to suit varying conditions of wind strength and angle.

One can visualize tankers, carrying liquid cargo, and not requiring cargo handling gear, to have stayed masts, whereas certain small commercial fishing vessels might wish to have no stays or shrouds whatsoever in order to ease the handling of fishing gear. Freighters might have either, or a combination of the two.

The rig and details that I favor the most is a stayed rig with every sail, boomless, loose-footed, and triangular, as in a jib, with the full length of the luff supported, and luff roller furling on a grooved stay with the sail controlled by a single corner, the clew, and a pair of sheets. When properly designed and constructed this rig has proven over the last decade to be the most reliable and the most maintenance free combined with the requirement of the least crew. Millions of miles have been sailed with luff roller-furling jibs and now a growing number of craft are also luff roller-furling their mainsails. Past problems in luff roller-furling were invariably attributable to poor engineering. Most of the difficulties and failures were foreseeable and could have been avoided.

HULL DEVELOPMENT

What hull form will be the most suitable for commercial sailing vessels? In order to derive maximum propulsion from her sails, the sail plan must have a generously long base. Therefore, a hull of sufficient length must be put under the sailplan. Fortunately, a long narrow hull is easier to drive and can be driven faster than a short stubby hull. Since in larger sailing vessels stability is of less importance than in smaller craft, it seems axiomatic that the sailing commercial vessels of the future should have lower displacement length ratios than motor vessels of the past. Thus their lengths should be relatively long compared to their displacement. Commercial sailing vessels of the past increased the base of their sailplan by having bowspirits and jib-booms at the stern. With our evermore crowded harbors it seems likely that the best way to get a long sail base today would be to employ the hull itself rather than use bowspirits, boomkins or boom overhangs. If the vessel is to have stayed masts or if its aftermast is to be stayed it will want a permanent backstay in order to simplify and de-skill deck jobs, since it would be ridiculous and highly undesirable to have running backstays on a large commercial vessel. Thus a relatively long, relatively light, relatively narrow, double-ender might make a suitable hull for the commercial vessel of the future. It is true that a long vessel will have slightly higher initial cost and operating costs than a shorter vessel, but it is deemed that this will be worthwhile up to an optimum trade off point.

Centerboards are expensive to build and maintain. Centerboard board trunks detract from cargo holds, and future motor-sailing cargo vessel might be better off without centerboards. Leeway can be reduced by applying a little thrust from the main engine to increase speed and reduce side-slip.

FUEL SAVING

Possibly the most important question to answer is how much fuel can a commercial motor sailing vessel of the future expect to save over a pure motor vessel? I think it is fairly safe to say that the smaller the vessel the larger the fuel saving percentage wise and the larger the vessel the lower the percent savables. Since a large vessel burns considerable fuel, even a 10%, 20%, or 30% saving could be very consdierable and worthwhile.

An expensive motor-sailor with a tall complex rig will save much more fuel than a much cheaper retrofit with a simple shore rig.

SUITABLE RIGS FOR FUTURE COMMERCIAL MOTOR SAILING VESSELS

Here again optimum tradeoff points will have to be established based on the commodity transported, the routes plied, and the expected fuel cost forecast for the life of the vessel.

RIGS THAT THE AUTHOR CONSIDERS UNSUITABLE OR LESS THAN PRACTICAL FOR FUTURE COMMERCIAL SAILING VESSELS OF OVER 2000 DWT (DWT: deadweight tons represents the carrying ability of the vessel. DWT = Loaded Displacement minus Light Ship. It is measured in long tons or metric tons and is a measure of the vessels earning capability.)

Square Rig: Too labor intensive and conditions aloft no longer acceptable to present day labor force. Not close enough winded. Too much windage. Poor motor sailers upwind.

Junk Rig: Full length battens, increase the cost of sails require too much maintenance and repair. Unsafe in hurricane conditions, in mid-ocean, in enormous seas.

Gaff: Labor intensive, not close enough winded, poor motor sailer hard on the wind.

Lateen: Labor intensive, too much movable top hamper.

All rigs of the past are deemed unsuitable because they are labor intensive.

CONCLUSION

At this date, the author considers the only suitable commercial rig to be the boomless, luff-roller furling marconi rig with sail rolling up outside of masts.

PROPULSION SYSTEMS

This author is very much in favor of controllable pitch propellers for motor-sailing commercial vessels and also cruising yachts of the present and future. Admittedly controllable pitch propellers are expensive in their initial cost and somewhat more expensive to maintain than a solid propeller but their day-in and day-out fuel saving should easily pay for these costs with increased profits from fuel saving and faster passages under sail and motor sailing.

All of the cruising yachts over sixty feet that I have designed in the last eighteen years have had three blades and were either controllable pitch propellers or self-feathering propellers, and these features are considered extremely important. The beauty of the controllable pitch propeller is that it will permit one to use a larger, slower turning propeller for greater efficiency. Feathering the propeller will prevent holding the boat back when in the 100% sailing mode. The three bladed controllable pitch propeller with large reduction gear actually gives many benefits in all modes including 100% powering, motor-sailing, and 100% sailing. A large propeller has the further advantage that it will make a vessel more maneuverable in harbor and less dependent on tugs and other outside help for berthing. When deriving part of the driving force from the wind and part from the engine, the propeller's pitch can be adjusted for optimum loading and efficiency.

Thus a large three bladed single screw on the centerline, well protected by a sturdy skeg, is a very efficient propulser for a motorsailing merchant vessel or a yacht.

MANEUVERING

One can visualize vessels that have bow thrusters to further help maneuver in harbor to obviate harbor-tug charges. When pinned against the key wall an ample bow thruster can be very helpful.

MECHANIZED SQUARE SAILS

We presently have a 100-foot brigantine under construction that will have all of its sails electric furling. Six sails will be fore-and-aft luff roller furling sails, and three will be squaresails that roll up like window blinds on the forward side of the yards (as the French have done manually for over 100 years). The owner plans to cruise with the trade winds and can thus make good use of the square sails. On the other hand a money earning commercial vessel that had to make passages in any direction and at any time of year would find that the fore-and-aft rig would be much more useful. It would amortize its cost faster and would be more flexible than a square rigger that cannot motor-sail as close to the wind as can a fore-and-after, that could strap flat and motor- ail almost into the eye of the wind, while at the same time reducing rolling. A wind stabilized vessel is not only more comfortable but increases its hull efficiency and its propeller efficiency.

One should further note that in a vessel of several hundred feet in length, that is not overly burdensome, that one could expect fairly high speeds which would mean that the apparent wind would be further forward than it is on yachts of less than 100 feet. Many operators would not permit their vessels to ever go below 10 knots, selcting to start their engines whenever the winds were insufffficent. In many cases the vessels would be motor-sailing with the apparent wind quite far forward, making the close winded for-and-aft rig all the more desirable. If the sails are properly trimmed and full, it is evident, both analytically and in practice, that a useful thrust is developed, and considerable fuel can be saved.

A detailed economic study of initial costs, operating costs at various speeds and cargo value would have to be made to determine optimum length in various trades. It is, however, safe to say that one could expect the length of a sailing motor sailer to be 10% to 20% longer than her equivalent vessel that is purely powered. Another way of stating this is that the additional initial cost incurred by additional length would be worth it over the years because of the additional speed permitted by length's three great advantages: 1) permit a vessel to go faster because of her greater speed length ratio and, 2) permit her to go faster because she would have a longer base for her sail plan and thus could carry more sail, and 3) permit greater speed because of more favorable (lower) displacement-length ratio. In arguing in favor of additional length I cannot over emphasize these advantages of length. It would not be necessary to let costs soar unduly with the additional length, for one could elect to narrow the beam of the vessel somewhat in order to partly offset material and displacement increases.

OPTIMUM MOTOR-SAILING CONFIGURATION

My wildest and most futuristic idea and the one that the shipping industry and the yachting public will have the hardest time understanding and accepting is what I consider my best idea. What is this idea that I hesitate to enunciate for fear of being laughed at? Actually it is not so much the fear of ridicule as much as it is the difficulty of doing the subject justice without writing an entire paper on the specific concept.

In a nutshell the "wild idea" is that it is so difficult and expensive to put an adequate rig and sailplan on a large merchantman that one might do better to get the wind force horse power from a sailing towboat, and thus not need to put a rig on cargo vessels whose decks are already encumbered with lots of bulky cargo handling gear. Hence the sailing rig would go on the towboat about to be described. The barges and old merchantships being used as barges with their engines and propellers removed could keep their self unloading cranes, masts and boom and other deck gear intact, since they would always be towed.

The sailing towboat concept permits the naval architect the marvelous design latitude of being able to put any rig he wishes on any hull configuration that suits the rig best.

Thus, there would be no mast height limitation because the sailing towboats could let harbor tugs take barges or towed vessels to and from their berths while the lofty sailing towboats remained "outside."

IDEAL SAILING TOWBOAT HULL

Since we want maximum stability to carry sail and minimum weight, minimum resistance and maximum speed when running without a tow, what hull configuration should we choose?

My conclusion, and this is the wildest part and the hardest part for me to swallow, is that we want a giant catamaran. I can visualize a gigantic catamaran consisting of two tubular hulls that could be circular in section, so that seas would break over these whaleback hulls and they would be partly awash much of the time.

A deck made of expanded metal 20, 30, or even more feet above the water would not be bothered by seas breaking on the deck, for water would immediately drain through the mesh. The longer and the wider such a catamaran would be the less it would be vulnerable to the motion of the seas. Also the longer and wider the catamaran, the taller the rig could be made. The conning tower would jut out of the starboard hull and would resemble a combination of a submarine conning tower and an aircraft carrier's "island." A tall conning tower well above the ocean and also out of the way of sails, would have multiple advantages.

If such a towboat were large enough it would be very much like a super-tanker that could spend much of its life outside of harbors while simply delivering its barges at the mouths of harbors where harbor tugs could take them the rest of the way.

One of the great advantages of such a long and wide sail platform is that it would permit enormously tall masts and the sails would reach up to where the wind blows harder and enormous amounts of horsepower could be taken out of the wind and converted to useful propulsion. Remembering that <u>the force of the wind varies as the square of the velocity</u>, we can appreciate how powerful a truely tall rig would be, further remembering that the higher you go the harder it blows.

To visualize the size of such a craft one could go to the Southstreet Seaport, step on the deck of the Peking and look up at her enormous rig and say to ones self that a catamaran could be built that has a rig two to three times larger than the Peking's. Such a vessel could sail at twenty to forty knots light and could take on enormous tow loads.

Such a giant catamaran would have twin screws and whenever the winds were light it could tow as fast or faster than normal ocean-going tugs.

Actually, an advantage of the catamaran configuration would be that when the catamaran were light and going to meet a new tow she could operate at substantially faster speeds than the normal tug that has too much horsepower for the short length of its hull.

I have had this idea for many years but hesitated to enunciate it because I was afraid of being thought completely mad, or on the other hand and even more serious, have someone steal the idea. I have now reached the ripe old age that I no longer care if people think I am mad. People have thought so before and been wrong. Also I am less afraid of having someone steal the idea, for I would like to see such a giant catamaran in my lifetime, preferably of my design, but, if necessary to someone else's rather than not having it exist at all while I am still around to see it.

WATER IMPELLER ELECTRIC GENERATING

The aforementioned research brignatine has a 4.5 to 1 reduction gear and its 51 inch diameter propeller will on occasion be used as an impeller to generate electricity when there is sufficient wind and the drag is either acceptable or negligible. This research vessel will have two alternators driven by the main shaft with the engine engaged or disengaged. The alternators can be used by exciting the armatures or can be run free without exciting the armatures. This arrangement permits flexible use of one or two alternators to charge two banks of 110 volt batteries from which we can desalinate sea water, drive refrigeration compressors and otherwise contribute to other shipboard electrical needs.

The brigantine presently under construction at the Palmer Johnson Shipyard in Sturgeon Bay, Wisconsin, will also have electric solar cells in order to further generate electricity.

POWER STORAGE

Since we are talking about futuristic engineering, it is safe to assume that our means of storing electric energy is going to improve considerably for there is a great need for such an improvement. Man is a versatile creature and where there is a need and a market, he can usually produce. Hence, one might expect an improved lead-acid battery or an entirely other means of storing electricity. Such a storage device would be very valuable for storing the sun's energy when it is shining bright in order to use the electricity at night and when it is overcast. In a like fashion a giant sailing catamaran or whatever other sailing commerical vessel we wish to consider could have oversized peopellers that could act as impellers to turn generators when the wind blows hard. At such times the hull can use for its own propulsion.

Might it be possible, decades in the future, to build a huge catamaran, electric storage vessel, that consists primarily of electric storage cells, two propeller-impellers at the stern, and a powerful electric generating system attached to the shaft. When this catamaran were towed through the water by the giant towing sailing catamaran it could store energy within the storage catamaran, and this bargelike vessel could be taken to various places where electricity is needed. Small towns could draw from it for certain periods of time. Wild as this may seem, we might consider that fuel oil may in one or two generations cost ten to twenty times more than it does today. At such a time man will have to resort to other means of getting electricity than our present day means and this is only one vague possible suggestion.

I am sure that we already have the technology to build the sailing catamaran towboat and I also feel that we could build a catamaran generating barge that could generate quantities of electricity, but I think the missing link is the storage batteries. World War I to World War II submarines could operate underwater, at reduced speed, for a limited number of hours on batteries only. Since then improvements have been made but much larger steps forward are needed. Obviously such an electric storage system would be of great value for storing electric energy generated by various means, including windmills ashore. The energy stored when the wind blows hard could be used during periods when there is little or no wind.

A few diesel electric drives have been operating for the last decade, using silicon controlled rectifiers. Such SCR drives could readily be modified to use their electric motors as generators for generating electricity while vessels are under sail. A sailing vessel so equipped would do well to have substantial additional sail to spread in order to be able to overcome the impeller drag. I can visualize gigantic rigs with multiple sails that can be readily rolled in or out as the conditions require.

For the last seven seasons a yacht of our design has been spreading a gigantic jib of 3,600 sq. ft. in 20 seconds and putting it away in the same amount of time. It takes very little imagination to be able to visualize doubling the size of this sail and making it substantially more rugged for commercial use.

THE FAN STAYSAIL SCHOONER RIG

The fan staysail schooner rig is the one I favor for large commercial vessels because it is a means of spreading the maximum amount of sail on a given length vessel with all sails controllable from one corner, their clew. The term "fan" is simply to indicate that the mizzen is raked aft and the foremast is raked forward and all intermediate masts radiate from approximately the same point well below the vessel on the sail plan. There is nothing new about this concept for even the Mayflower and the Nina and the Pinta and quite a few others had foremasts that raked well forward as do Chinese junks in order to catch more wind.

If one visualizes a rectangle, above the hull of a vessel, on the sail plan, the "fan rig" is simply a way of using up as much of the area within that rectangle as possible without protruding over the stern or going out over the bow. "Fanning" the spars has the further advantage that it does not overly compress the foremast and the mizzen but shares the load slightly more equitably with the masts between.

ILL ADVISED PROJECTS

There are quite a few projects in the wind and some even under construction that seem doomed to failure. At the 1980 Com-Sail Conference in London, some speakers got up and argued that square riggers had proven themselves in the past (a correct statement) and that they were possible to build today (another correct statement) and that therefore we should build a square rigger today (incorrect conclusion). The enormous error or oversight in this argument is that the labor pool's standards have changed enormously in the years between the end of sail and the present shortfall in fuel. Mankind has undergone deep sociological changes. This is a polite way of saying that man wants more money for doing less work!

Square riggers are the very best sail training vessels for cadets and other youths, but in commercial trade they are obsolete.

Present day man will not be found in sufficient numbers to man the great square riggers of the past. On a lovely spring day there would be tens of thousands of applicants. The summer and the fall would cut the number down enormously and by the time winter came there would be none left eho cared to go aloft in sub-zero weather when the wind is blowing over 40 knots, with the rigging and the yards covered with ice. It is safe to say that sociologically square riggers that require men to go aloft to furl sails are completely unacceptable in our time. Since this paper is not on the subject of sociological change I shall not delve into whether this is good or bad.

This brings us to the second stage of fallacious thinking. There are those who accept the obvious fact that man does not want to go aloft in a blizzard, but then jump to the conclusion that it would be easy to mechanize squaresails so that no one need go aloft. The thousands of lines that were required to handle the squaresails of the past cannot be eliminated overnight. Even with our three yards on the aforementioned brigantine research vessel, it will take eight lines to "brace the yards" (six braces and 2 sheets. To roller set the three square sails will require trimming six sheets while simultaneously rotating the "sail winders". The conclusion is that it is much easier to mechanize (and elctronically automate) fore-and-aft sails than square sails.

LACK OF ACTION

There is a lethargic lack of action in converting to commercial sail. We know that Japan has actively entered into the motor-sailing field. They are operating a 1,600 ton vessel with an undersized sail plan to study the possibility of scaling upwards. Reports indicate that this vessel saves about 5% in fuel because of the sails, although her overall fuel saving is 50% because of many other fuel saving features.

We know very little of what Russia is doing, although apparently they are doing considerably more than the USA. Many people ask, "Why aren't we doing something about building motor-sailing commercial vessels"?

COMMERCIAL SAIL DILEMMA

Developing commercial sail would most efficiently be effected as are all evolutionary developments: step by step. Unfortunately a "practical sized" commercial vessel is somewhere between 16,000 DWT and 48,000 DWT and this would represent a huge step. To put sail on this size vessel in 1982 might well be too big, too soon. Mini-cargo ships of 2000 to 4000 DWT are hard to retrofit and new designs and new construction is badly needed. No ship owner or ship operator has of this date stepped forward and ordered such a new vessel. How can one step up vigorously if they will not take the first step?

KITES

Kites are a means of getting a very strong force on a single line. Surprising as it may seem, kites can and have been made to pull vessels upwind. In evaluating kites, one must immediately get rid of the notion that the tethering line of the kite has to pull dead downwind and that a vessel following it must follow the line on either side of it. A vessel fitted with proper anti-leeway planes (centerboards or keels) can sail at approximately 60 degrees or 70 degrees from its towline. This would lead one to the concept that a vessel can sail at about 130 degrees each side of the dead to leeward line. Twice that angle is 260 degrees, and this would only exclude about 100 degrees from the total 360 degrees in a circle. I believe that the kite flying, boat towing, enthusiasts might claim the ability of tacking through 90 degrees.

Admittedly, flying gigantic kites to tow large ships sounds outlandish but possibly far less outlandish than landing men on the moon or having an aircraft that can go into space and return. Kite-flying would of course have to be considerably more developed on experimental prototypes well before it could be considered economically feasible. Mankind, however, may well be up to this technology in the next two or three decades, but I rather doubt it. There would be no NASA budget for such a "nutty project."

I would love to have a $30,000,000 budget over a five year period to develop a 100 foot yacht, research vessel, or small scale prototype cargo carrier. It would take this size and length program to just take a look!

I have no idea whether the kite would be a manned glider or whether it would have lighter-than-air gases to help it, or whether it would be more of an airplane with a small engine permitting it to join or leave the towboat at will. I haven't the vaguest idea of whether such a kite could be anchored in harbors before the towed vessel entered on its own or whether it would go land on some landing field or otherwise be deflated or stowed when not in use.

These are all admittedly rather far out concepts that are not just right around the corner, for the main and simple reason that sufficient funds are not apt to become available in the near future. But on the other hand, as fuel reaches the astronomic costs that most logical people realize it will, man will surely make an immense effort to harness the enormous energy that is constantly passing over our heads unused from two hundred feet to a few thousand feet up.

In order not to sound too impractical and overly optimistic, one would have to point out that one of the great complexities and difficulties of being kite-towed would be that of one ship's kite lines tangling another ship's kite line. Scheduling would be relatively easy when there were few kites flying in the world, but if they ever became numerous, very strict and closely regulated routing would of course be necessary.

Before leaving the subject of kite-towed vessels, I would like to say that I hope that some enterprising, and venturesome, and fun-loving yachtsman would design a day-sailing catamaran that had a traveler right across from one hull to the other, forward of midships and experiment flying various types of kites including "dynamic kites." After all, a kite is only a sail that is somewhat more at liberty than the usual sail. The kite-sail is a very intriguing substitute for a mast in that the line is relatively light in weight and affects the stability of the vessel much less severely. A catamaran could shift the tethering point along a traveler in such a way that the kite two rope pull would not tend to tip the vessel over but would lift both hulls equally.

I should add further that the boat towing kites that have been experimented with in England from the Island of Wight on the Solent have been "dynamic kites" that are tethered by two lines and do not simply lie still in the sky as does a child's kite, but rather gyrate at rather great speed thus developing substantially more towrope tension and hence horsepower.

Many of the subjects I have touched on in this paper could each constitute a paper or a series of papers. Thus I hope you will excuse my somewhat abrupt dealings with some of these subjects. In many instances subjects have been mentioned to give out data which does not yet exist.

Before giving up on the idea of kites, one should remind one's self that there is immense kinetic energy way up high, and that it is up to a man's imagination and ability to harness it. In other words, it has immense potential so let's not give up too fast. Usually when man sets his mind to tap a highly valuable commodity, he usually eventually achieves its commercialization. The question of how soon and by what means will we harness the winds at 5,000 feet and 10,000 feet, is not resolved but is extremely intriguing.

LEARNING LESSONS FROM OTHER DISCIPLINES

At the beginning of this century, the science of yacht design and the art of yacht construction learned many lessons from commercial fishing boats and working sailing vessels that were then making a living with the wind as their prime-mover.

Sailing commercial vessels have now been dead for decades in most part of the world, and if one wants to return to sail in commercial fishing or other commercial sailing ventures it would definitely be well to take a close look at what yachtsmen have learned over the decades. Literally billions of dollars have been spent and billions of sea-miles have been sailed, since the Wright brothers flew in 1903. Since that time, a great deal has been learned and anyone wishing to commercialize sail would do well to take a very close look at yacht rigs and yacht practice. While this might seem a fairly obvious suggestion, one might note that in fact the nation that is spending the most money at the present time developing commercial sail that we know of is Japan, and that they seem to have paid very little attention to yacht sailing practice.

Anyone aware of the immense amount of technology that has been developed for hardware, sailmaking, and rig design and construction should make use of that technology. It seems a great pity that the Japanese are in effect starting from scratch with sails that hinge and fold, in a way that inevitably seems to lead to having too small a sail when in use and too great a bulk causing windage when not in use. Woven materials have for centuries, and even thousands of years, shown that they are extremely convenient because they can be furled to a small size and extended to a large size when needed. Sails made of woven material can be lowered when hurricanes and typhoons are expected. In the last 3,000 years no one has found anything more versatile, stronger, lighter and more able to quickly take the shape desired on either tack than a soft sail.

SUMMATION AND CONCLUSION

In the last 10 years and particularly the last two, great steps have been taken in simplifying sail handling. Today a 110-pound girl can set sails 10 times faster than five strong men could have done 10 years ago.

In the next 10 years an enormous change will take place in the rigging of a large fraction of the U.S. and the world's cruising sail boat yachting fleet in order to de-skill sailhandling, to make owners less dependent on numerous expert sailors.

On the other hand, progress in commercial sail development will <u>initially</u> be painfully and often discouragingly slow. Clients for new motor sailing construction will be extremely rare. Hopefully a few brave, venturesome, or altruistic businessmen or entrepreneurs will step forward.

JAPAN WILL TAKE A COMMANDING LEAD! in the world in commercial motorsailing operations. They will surely produce the most fuel efficient ships in the world in the next two decades, because they have more energy, courage, farsightedness, and true understanding of the fabulous rewards to be gained from dynamism than any other nation on earth.

The rest of us in the Eastern and Western world will fall woefully behind in motorsailing commercial sail development (and many other things) because of lethargy, cowardice, featherbedding, bureaucracy, timidity, incompetence and general lack of imagination, and particularly violating the principles of entrepreneurship.

Having let Japan get a huge jump on everybody, the rest of the world will slowly wake up and buy ships from Japan and eventually copy her and try to compete with her.

Japan left us all behind in binoculars, cameras, radios, tape recorders, motorcycles, television sets, radar, automobiles. and quite a few other things. Why not let them completely outperform us in commercial sailing ships as well?

SAIL-ASSISTED COMMERCIAL FISHING VESSEL WORKSHOP SUMMARY

Christopher M. Dewees, Editor
Marine Fisheries Specialist
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University of California
Davis, California

On November 3, 1982, a one-day workshop on sail-assisted fishing vessels was held in Sausalito, California. It was sponsored by the University of California Sea Grant Marine Advisory Program, Ocean Carriers Corporation, University of Florida Sea Grant College Program, University of South Florida College of Engineering and the Pacific Coast Federation of Fishermen's Associations, Inc. Additional support was received from the City of Sausalito and the U.S. Army Corps of Engineers.

The purpose of the workshop was to present and discuss practical information about the use of sails on fishing vessels. This is a concise summary of what took place at the meeting. Also included is a brief bibliography and a list of participants. For further details on each topic contact the individual speakers. (Christopher M. Dewees, Editor).

CONTENTS

I. Design and Realities of Sail-Assisted Fishing Vessels - John Shortall III, N.A., University of South Florida, College of Engineering

In the Gulf of Mexico fisheries fuel costs are shutting down many fishermen, especially shrimpers. Approximately 50 percent of the shrimpers' costs and 30 percent of the Gulf longliners' costs are fuel related. Sea Grant funded research in Florida has been directed towards retrofitting and the snapper-grouper longline fishery. Retrofitting of shrimpers is difficult because of the large amount of complex deck equipment. One can retrofit a vessel for the snapper-grouper fishery for approximately $10,000.

Fuel prices will increase in the long run. Shortall feels that the following are critical needs for successful sail-assist vessels:

1. Retrofit must show economic gains over a 15-year life span.
2. Sail rigs must be simple with no extra crew required.
3. There should be minimum interference of fishing operations by the rigging (consider unstayed masts).
4. Clean, low superstructures are needed.
5. The heel angle should be 10° or less to minimize crew fatigue. (Editor's note: Some audience members felt 20° heel was acceptable.)
6. Consistent winds are needed; a minimum of a 10 knot average.
7. Bridge clearance by masts is important.
8. The fishing grounds must be at least 150 miles away unless the sails are used during fishing operations.
9. Sail and engine must be used at the same time. Turning the prop at several hundred R.P.M. reduces propeller drag.

Some of the problem areas, especially with retrofitting of vessels, include:

1. Ballast tradeoffs.
2. Coping with the variable center of gravity and variable displacement due to changes in fuel loads and filling of the fish hold. Center of gravity needs to be lower.
3. Lateral plane area.
4. Developing good rudders and steering systems.
5. Dealing with the shallow waters found in Florida waters.
6. Developing balanced sailing rigs.
7. Stayed or unstayed masts.
8. Type of rig for use: gaff, bermuda, ketch, schooner.
9. Being able to predict motor-sailing performance.

Some overall issues need to be addressed also. The merchant marine industry currently favors coal over sail-assist. Builders seem to be much more resistant to sail-assist vessels than fishermen. Perhaps they don't want to change their traditional profitable building methods. Others are negative on sail-assist and they say that other fuel conservation methods (clean bottoms, lower speeds, etc.) should be used instead. Finally, the value of single shot experiments in sail-assist vessels is often criticized.

The choice between retrofitting or using new designs is difficult. At this time the high cost of new designs makes retrofitting more attractive economically. Several builders have tried to adapt yacht designs to fishing situations. It seems better to make sure that the vessel will be a good fishing vessel rather than a yacht. Catamarans need to be considered also. Over 15,000 are used in India. Their wide beam could reduce the need for otter doors on trawls; they have lots of deck space; and they are easily beached for maintenance.

II. Overview of Economic Studies of Sail-Assisted Fishing Vessels - Christopher M. Dewees, Marine Fisheries Specialist, Sea Grant Marine Advisory Program, University of California, Davis

It is difficult to generalize about sail-assisted fishing vessels; the situation is different for each individual and each fishery. This variability is reflected in economic studies. The economic reports often reflect the interests of the authors who range from diesel engine salesmen to romantic sailors.

Since 1967 fuel prices have risen 1,100 percent (1,000 percent since 1973) while fish prices have risen 400 percent. This high price increase has spurred interest in sail-assisted fishing vessels. A University of Hawaii study estimates that there are 50 to 75 sail-assist fishing vessels currently operating in the Pacific. In my review of the economic literature, the following major points become clear:

1. The high cost of technology and high interest rates make sail-assisted fishing vessels difficult to justify economically. Costs range from $10,000 for retrofitting to $400,000 for a new vessel (an equivalent used diesel vessel might cost $200,000).

2. The fuel bill must be a significant portion of the vessel's variable (operating) costs. While Gulf of Mexico shrimpers spend 57 percent of their variable costs on fuel, West Coast fishermen devote 5 to 25 percent of their costs typically to fuel.

3. On the Pacific Coast the most likely to benefit from sail-assist are fishermen with long trips to the grounds. The offshore albacore fleet and Seattle-based vessels traveling to Alaska are the best examples.

4. Fuel savings must be balanced with a loss in hold capacity of up to 50 percent and loss of deck space. If another crew

member has to be added to handle the sails, sail-assist probably won't be economically viable. A loss of speed (time) needs to be considered; this could add up to the loss of one to two trips per year or the fisherman could "miss the bite."

5. One needs to combine sail-assist with other fuel conservation measures such as reduced engine R.P.M., a cleaner bottom, reduced weight, efficient hull design, use of passive fishing methods, variable pitch or feathering propellers, and fuel monitoring devices.

6. In order for sail-assist to become more widely used, a continued rise in fuel costs is needed (this is likely). Also, the cost of the technology for both retrofitting and new vessels must be lower relative to the cost of available used diesel-powered fishing vessels. Tax credits and/or loan subsidies as proposed in S.B. 1356 would encourage adoption of the technology.

7. Careful economic analysis that considers life costs, sensitivity analysis and time to payback is needed. Past economic studies have generally failed to quantify sail-assist's value for coming-home ability, reduced towing insurance, reduced engine wear, comfort (less roll), and the value of the sailing lifestyle. Additional costs that need to be quantified include: loss of time/speed, limiting of fishing alternatives or lack of possible diversification due to vessel design, availability of wind, cost of learning to sail.

III. Practical Sails for Fishing Vessels - Peter Sutter, Sutter Sails, Sausalito

"My knowledge of fishing and its industry is limited and my fishing abilities are even less. My only claim to fame being that I caught six mahimahi and two blue fin tuna on a recent trip home from Hawaii. One of the tuna was so big we threw him back. So I can say at least I saved one for the fishermen to catch.

"I know my talk is supposed to be in the area of sails, however, I do wish to voice my opinions of hulls and rigs as well as sails; and in this talk I am only considering the fishing vessel that has been designed as a sailing fishing vessel with a power plant capable of sustaining hull speed when necessary, and that this vessel will be used by the offshore fisherman.

"A sailing fishing vessel must be capable of moving from one area to another as well as its motor driven competitior; and not always can sails alone supply the power to do this. In this respect the hull shape chosen for the sailing vessel is the most important factor. Very few of the recently built sail-assisted fishing vessel hulls I see are designed for ease of movement through the water (the real fuel saver). The modern designs are quite beamy with regard to their length, totally losing the cleaner sailing lines provided by narrower hulls.

"There is no denying the fact that toward the end of the Grand Banks Schooner era, the hull design that had evolved was a very fast, easily moved hull (provided you didn't mind getting wet and had a large crew). The hull was narrow and deep with plenty of deadrise through the mid-ship section. Its rig was low and powerful. The maximum length vessels were in the neighborhood of 135 to 140 feet and held about 70 tons of fish. The smaller vessels were about 70 feet and could hold up to 40 tons. All of the vessels enjoyed good sailing capabilities whether empty or loaded primarily because of their hull shapes and their low aspect ratio rigs--most of them were gaff headers.

"Forty or more years have elapsed since these schooners were replaced by fully powered vessels. What I am trying to say is that today's designers of offshore sail-assisted fishing vessels should take a long look at those vessels developed in the past.

"Too often we see the ketch's lower shroud spread so far apart fore and aft that a meaningful sized staysail cannot be built. The jobstay's turnbuckle should be eliminated entirely and that stay be tensioned with the backstay on the ketch and the triatic and main backstay on the schooner. The sailtrack on the spars should be either 7/8 or 1 inch external U.S. standard track because the slides for external track are much stronger than the nylon slides made for the internal track.

"The running rigging should be as simple as possible. Halyards should be of non-stretch braided dacron; lazy jacks to help contain the sails when lowering are very seldom seen on jibheaded rigs but should be employed; boom sheetleads should be placed on the boom to strengthen the boom when the sail is reefed, not at the boom's end; sheeting arrangements that minimize the sheet length when it is being overhauled or slacked should be employed. The list goes on and on, but the K.I.S.S. (Keep it Simple, Stupid) syndrome should always be followed.

"Sails are pretty standard nowadays, but three important aspects of them must be considered: shape, strength and longevity, and ease of handling.

1. Shape. Sails should be cut fuller than those for the average cruising yacht because the fisherman is concerned with power and not with winning races. His vessel is not close winded, so why start out with a flat sail. As the sail is reefed, it automatically flattens itself.

2. Strength and longevity. In the 40 years since those great fishing schooners disappeared, much has happened in sail design, construction and materials. The greatest advance is dacron sail cloth. It first became available in limited amounts 30

years ago and it was about 20 years before the sailmaking industry really understood how to use it. A good part of this time, for the older sailmakers at least, was spent in getting away from the methods used in cotton sails.

One thing that has held true for me, where strength and longevity are considered, is the weight of fabric. The heavier the fabric, the longer it is going to last. Today we are getting sails back in the loft that are 25 years old and have made a couple of trips around the world. After some resewing they are ready for many more years of use. Most of these sails are of 9 ounce or heavier dacron and sun damage has not occurred. Nine ounce should be used in a 40 to 45 foot boat and 10.5 ounce in boats in the 50 to 60 foot range. The sails should be cut without batten pockets or roach which are the real problem areas on most sails. Corners must be stronger and heavier than for the usual cruising sail. If the mainsail and mizzen are expected to be used as trysails, the top third of the sail should be made of heavier weight dacron.

Seams should be broader than normal to provide width for double stitching later. The sails should be triple stitched initially and the two edge rows should be through both thicknesses of cloth. If possible, the dacron should be ordered with its natural woven selvage edge rather than the burned edge which is normal practice for the manufacturers. The natural edge provides a much stronger edge that will not unravel through chaffing as time goes on.

3. Ease of handling. Ease of handling heavier weight sails comes in three ways: knowing how to handle them (which I'll touch on later); the degree of softness of the dacron cloth itself; and the rigging of the boat. For the fisherman's purposes, the softer the fabric the better. Some fabric is woven and finished for the cruising yachtsman that is called soft. It is called Bermuda cloth, but even this fabric could be softer. I think as the fishermen's demands increase, a cloth will be woven that will meet their needs.

"In closing I want to touch on education. We all want the fisherman to use sails to help defray fuel costs. But how can we expect the fisherman to be able to use his sails to their best advantage? Few fishermen have been around sailboats all their lives. There must be a place within Sea Grant or the fishing industry for instruction. Someone is needed who is willing to spend the time on a voyage or two to teach the fisherman a new type of power and a whole new set of gear. Call me anytime."

IV. Panel Discussion - Morgan and David Davies, fishermen, boat builders and boat designers; J. P. Hartog, Naval Architect, Holland Marine; Miklos Kossa, Naval Architect; John Shortall III, Naval Architect; Christopher M. Dewees, Marine Fisheries Specialist

A free-wheeling discussion among panel members and the audience reviewed the earlier talks, answered questions on specific situations and brought up new issues. The problem of making the non-sailing fisherman skilled enough in sailing to adopt a sail-assisted vessel was an important issue. The trade-off between an easy to move narrow hull shape and the corresponding loss of hold capacity was identified as a key economic and design issue. Problems with retrofitting current fishing vessels with hulls unsuited for efficient sailing was debated. The use of variable pitched propellers was encouraged by several panel members. More information and education in a form usable to the fisherman about sail-assisted fishing vessels is needed.

HOME-BUILT REFRIGERATION SYSTEMS FOR SMALL FISHING VESSELS

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I have been a fisherman for the last 30 years, and in this paper I will try to explain what I have been able to accomplish, for more profit, in the refrigeration field.

The object of this system is to spray cold water on the fish, rather then put them on ice. You will no longer have to wait on the ice house to open, carry the extra weight, stack fish, or come home early. Make you wonder? Well keep reading. This really works.

That woman of yours may get upset when you steal the air-conditioning out of the family car, but that is what we use. You can even use the blower unit in the cabin for hot summer days. I am using one compressor to run two holds, a freezer, refrigerator, and you guessed it ---air-conditioning---. The average refrigeration engineer will say that it can't be done with an automobile air-conditioning compressor -- it's too small. What our advantage is, is that we are using raw water to cool the freon, not a radiator out in front of the car.

A few comments before I get into the hard stuff of building the unit.

I have found that the chill water will keep fish in superior condition, far better than ice. Think of putting your hand in a spray of 34 degree water, it turns blue very quick. Now put it into ice. What seems to happen is that the water spray remains cold and a heat shield can't build up as in ice. The temperature inside of the fish drops down to the 30's in minutes rather than hours. The critical temperature for bacteria is 41 degrees, above it it grows and below it becomes either dead or formant.

Let's talk a little about the problems that you might have. Most fish houses are not aware of this type of cooling, besides they like to sell you ice. Any good buyer can tell the condition of the product by the firmness of the eyes, smell, and texture of the flesh. The gills will start to turn white around the edges in our system. No problem, its just that the public is not aware that white gills mean cold fish. I forgot to mention the color. You don't have to sugar the water. The color remains almost the same as when they come out of the water. My clincher was when I brought in a 330 lb. whole Jew fish that had been in the cold for less than 12 hours. The hottest spot that we could find was 39 degrees on the backbone.

Ever see what a fish house does to lobster tails prior to shipment? Yep, they soak them in fresh iced water. Keep in mind that this system recirculates fresh water so don't mix fish with tails and shrimp.

On the operation of the fish hold -- you will end up with a series of coils on the bottom of the hold, supported by wood, with screen above to keep the product from being submerged in water or touching the coils. A pump mounted at the lowest point will pick up the water and spray it over the fish. If you want fresh fish, you use fresh water which freezes at 32 degrees and won't freeze the fish. If you want frozen, use salted sea water which can get as low as 28 degrees in liquid form and it will freeze the fish. This is similar to the brine system used for tuna. Remember if you forget to put fresh water in the hold before leaving the dock, and you end up using salt water, watch your hold temperature closely, you could end up freezing the load. That is one of the nice things about this system, you can just about ignore it other than being sure that the pump is working. The screen will be about 3 or 4 inches above the bottom of the hold. If the bottom of the hold is on a slant, don't worry about covering all of the coils with water. The spray will hit the coils which chills the water, freezing some of it. The run-off from the ice on the coils is what you are using. Most sytems use 20 to 50 gallons (76-190 lt.) of water in the hold.

Our system does not have to be left on all the time. Once you have a good supply of ice built up around the coils, the compressor can be shut off leaving the spray going. In other words, you don't have to listen to the engine running all night. I freeze 50 gallons of water in about 1½ hours which will last all night. Remember 41 degrees is the highest temperature that you want the hold.

As you have read this, you can see that the hold should be water tight. I have been able to glass some of the older style vessels to keep out the engine room and shaft water. The insulation is not critical other than for holding purposes. My present hold is made of tin, glassed over with 1" of styrofoam and 3/8" plywood on the outside.

A foam of blood and slime will cover the fish. This will act as a good insulator in case of engine failure. My markets would rather have the foam on the fish during delivery to keep them cold. It washes off with ease. Again, it is below 41 degrees and it is part of the fish -- no filter needed.

One last thing before I start on the mechanics. The sooner the fish are chilled the better. Just throw them in the hold, (gutted); don't worry about stacking.

O.K. on to the system. A lot of parts can be picked up at a junkyard, rather than the family car. Be sure that the system is charged before you tear one apart. Be sure to keep dirt and especially moisture out of all parts. This is a Freon 12 system.

COMPRESSOR

I have found that York compressors from a Ford with the four bolt three position type, are most abundant. If possible get the one with the valves on the head. Also include the hoses and tank (Suction Accumulator). This also gives you the electric 12 volt clutch, and the nipples to put in freon. If you have to buy the above separately, it can be very expensive. Pay attention to the end of the hoses. They have to adapt to flare fittings. In one case, I had to cut the hose and have the local parts house install a hydraulic fitting.

HEAT EXCHANGER

Many types are available. Be sure it is a salt water type. (No steel.) Use a pencil zinc on the salt water side. The type designed to cool will work. They have a small plug on the water side for the zinc. If you want to build your own, take about 10 feet of 1" soft copper and insert 2" of 3/8 soft copper inside. You can coil it or whatever, but silver solder the ends leaving a nipple so raw water can get around the smaller tube which will be cooling the freon. It's a little hard to get a zinc in this type but it is necessary. The standard type with horizontal tubes is very expensive. A keel cooler is best.

FILTER

Standard Freon - 12 type with fittings. (Watch the arrow.)

SIGHT GLASS

Flare type mounted so you can see it with ease.

EXPANSION VALVE

The external regulated type with capillary tube, which comes with various inserts. This is an easy way to get the right tonnage. Ninety percent of the systems will use a 3/4 ton insert. The capillary bulb is to be mounted with the small tube flat or upon the suction pipe leaving the hold. This controls the frost line.

SUCTION ACCUMULATOR

This is a tank on the suction side of the compressor which keeps the liquid freon from entering the compressor on start up. Watch the arrows or the way it comes out of the car.

VALVES

Use refrigeration valves only (Watch the arrow).

GAUGES

Pressure; Refrigeration type with Freon-12 readings. After the system has run awile, the low will be around 6 lbs. and high 100 lbs.

Temperature; Bulb type below 65 degrees. The bulb will be attached to the chill water pipe at a hole to measure water temp.

HOLD SPRAY PUMP

Centrifugal type. A rubber impellor creates heat. I found that a 1750 G.P.H. submersible bilge pump works well. The water will not be over its top and it will be working in the cold water so its life is quite long. It is important to put a loose fitting piece of fiberglass window screen around the bottom, held by a stainless clamp. This keeps the scales from jamming the impellor or plugging the spray holes. This pump will be attached via a rubber hose (for easy removal) to the 3/4" P.V.C pipe that circles the top of the hold. The spray holes in the pipe should be about the size of a round toothpick. Don't put too many holes, but be sure that they will spray on top of the fish no matter how full it is.

COPPER TUBING

All will be soft refrigeration sealed coils. Three-eighths" up to the expansion valve and ½" back to the compressor.

I have found that this copper is the cheapest way to go. It comes in 50' rolls and if you have a friend in refrigeration he should be able to get ½" for around $13.00 per roll. If nothing else, create your own refrigeration company. Once your system is going, the rest of the local fishermen will want one. Now the bad part on copper--salt and copper do not get along. I have been able to get around three years of service in salt water and much longer in fresh before having to change the hold coils. The average hold has between 75" and 100" of ½" pipe in them. The ½" copper will make a 180 degree bend with a spring bender in 4¼". If you have a handle bender, it can be done in 3¼".

Another way of putting coils in a hold is using surplus from the Navy. Good luck on the welding.

After the system has been put together according to the enclosed diagram and you think all nuts are sealed then to the important part. Put a small amount of freon in the system, and check with soap for leaks. This will save you from sucking in moisture, in case you goofed, when you put the external vacuum pump on. If no one in the area has a vacuum pump, and you can't rent one, then pull the pump out of an old refrigerator or freezer and use it. Once you are sure that there are no leaks and it has been pulled down to around 29 on the gauge, for several hours, it is time to put in an oil charge on the top side. This is the can that you get from the auto parts store that says "Oil Charge, Freon - 12. All this does is give the compressor oil on top. The compressor should be ¼ full in its crank-case with refrigeration oil.

The easy way to tell how much freon to put in, is to watch the sight glass, with compressor running, and gas being put in, is on the suction side. The bubbles will disappear and you will have pure liquid. Add a little extra. The suction accumulator acts as a holding tank.

On new and old systems, a drop of water will sometimes get in the expansion valve and either slow down or stop the freon. If this happens you will notice the frost creep down on the wrong side of the valve toward the small pipe. A quick way to clear the problem is to take a propane torch and warm up the valve. Be careful, don't get it too hot. What you are doing is melting the water, allowing it to flow to the filter which will catch it.

TANK COILS

A series of true 1 x 2's drilled and sawed, will give the form in which to lay the ½" O.D. pipe in. These then can be nailed back together. The holes should be 5/8" to allow for the saw cut. Place small blocks underneath to allow water to pass, and place a lattice of 1 x 2's flat on top leaving coils exposed to spray. Overlay this with good ¼" hardware cloth (double galvanized). Leave room in the corner or low spot for the pump. Keep the nearest coil at least 4" away. The wires, refrigeration pipes, and hold temp. gauge, can all enter up high. The draining and cleanup of the hold has to be figured in. Ordinary household bleach mixed with clean water will kill any bacteria and not hurt the copper much.

DIAGRAMS

The enclosed diagrams should give all the rest that you need.

This looks like a lot of trouble, but really I've used more words than necessary.

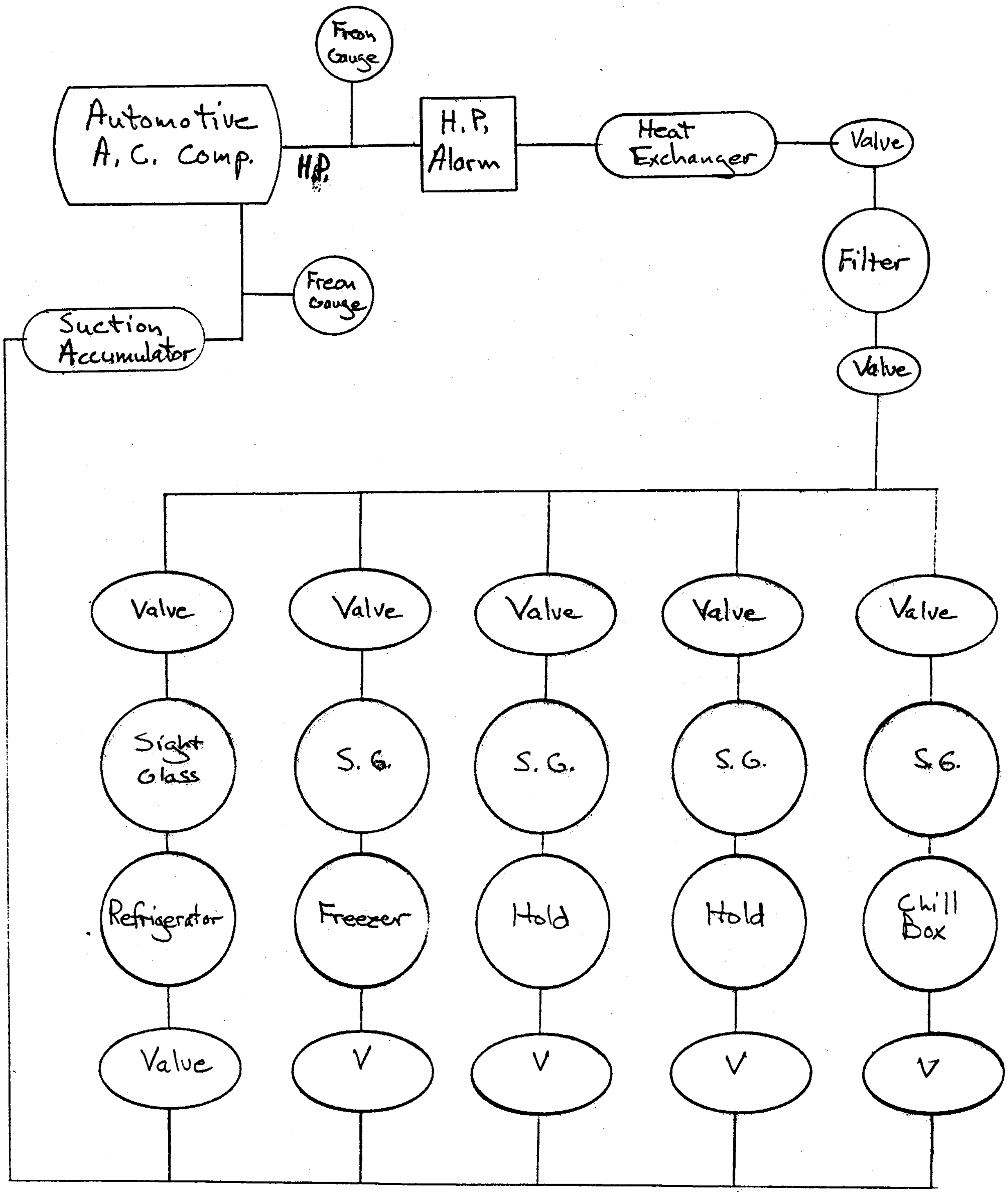
MORE

In all the sytems that I have built and helped build, I have yet to hear a complaint. I believe that the hardest thing to do is to mount the compressor and water pump. If you are not hurting for engine cooling water, then use the same pump, a large cooler for freon, and plumb the heat-exchanger in first before the engine. I have in a few cases used a jack-shaft, but that be an added cost.

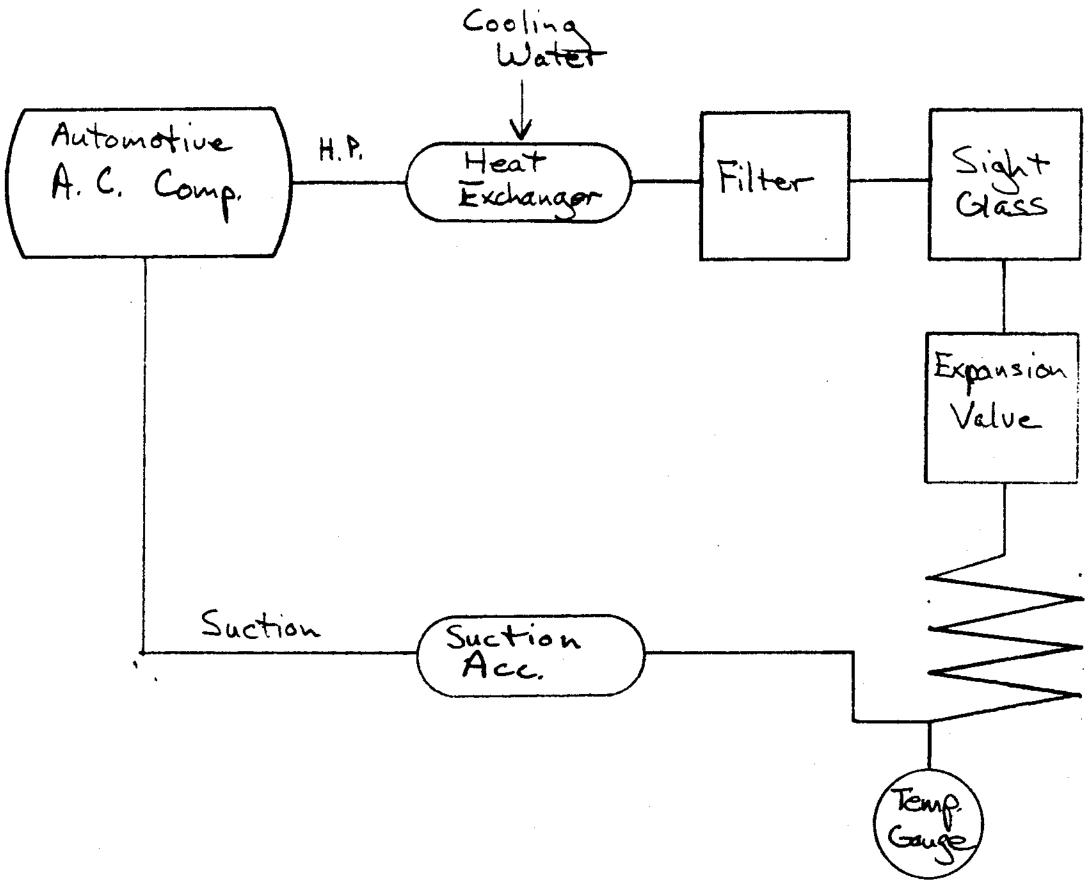
If someone in the area has an old ice maker, this will give you gauges and valves, possibly a heat exchanger. Don't hurry, check the salvage yards. Even temperature gauges can be found for scrap prices. A cold drink will tell you if the gauge works, besides most can be adjusted.

Use new or clean pipe. You don't want a speck of dirt inside.

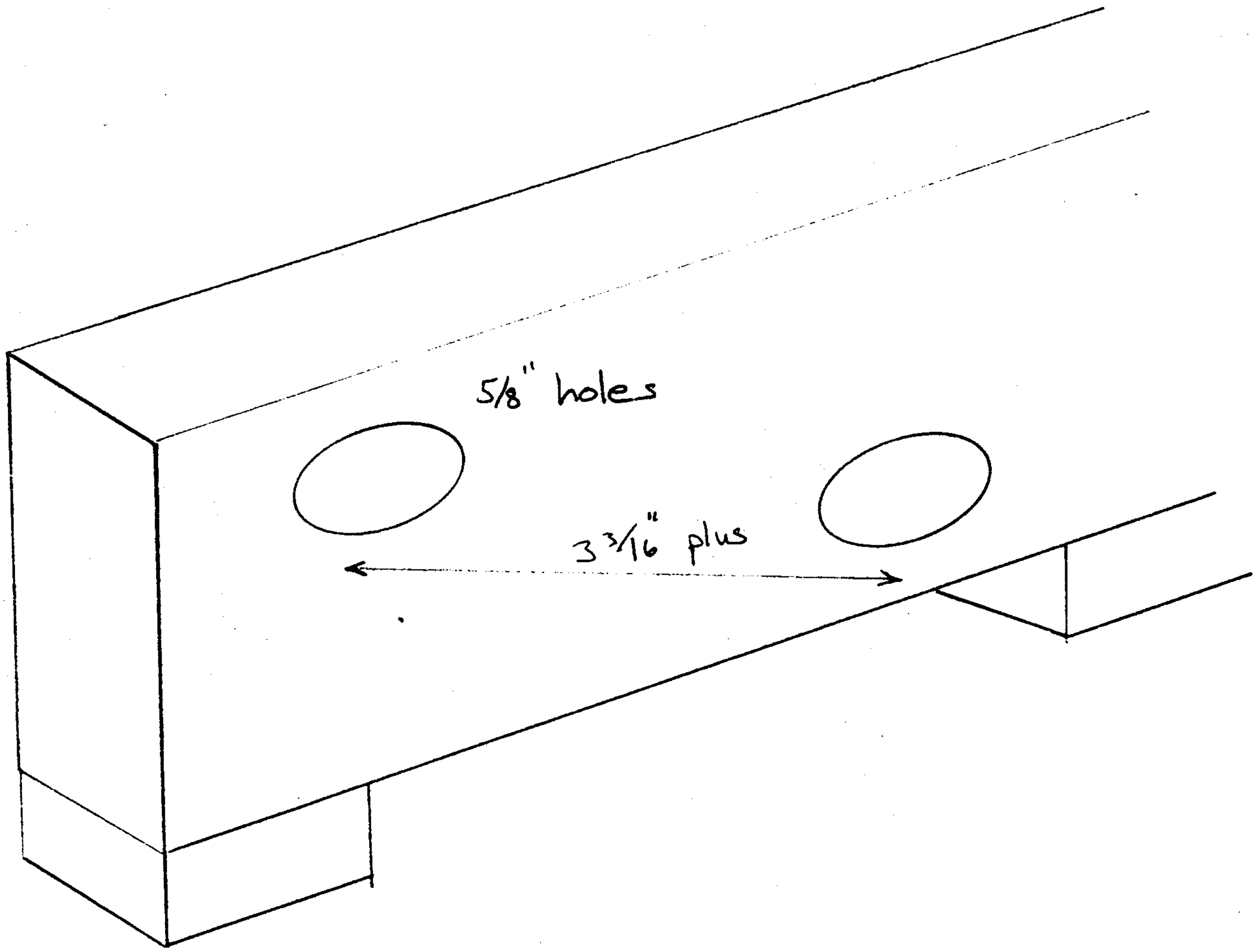
Complex System



Simple System



Tank Coils



SAIL-EQUIPPED MOTOR SHIPS - INTERIM SUMMARY

Nippon Kokan Japan

1. Introduction

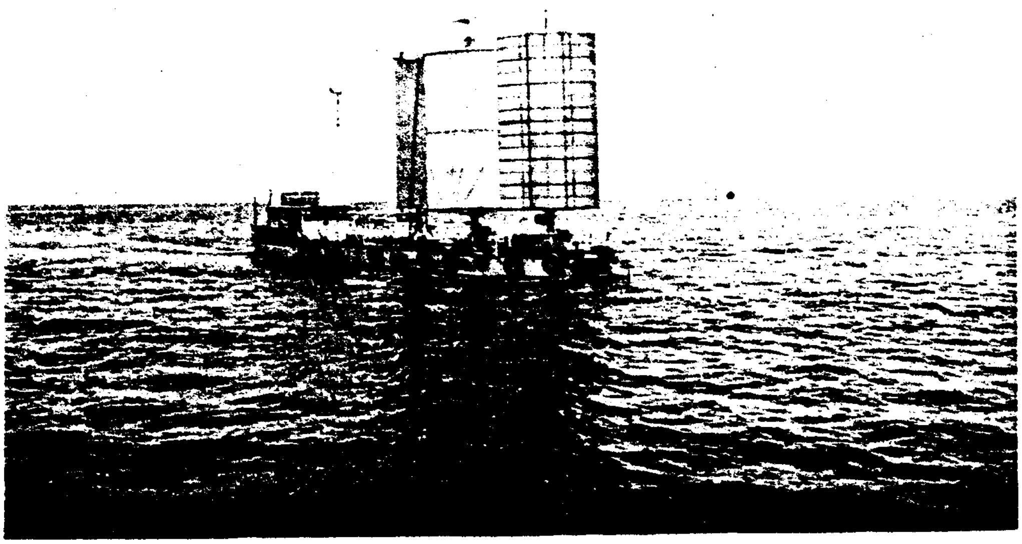
The drastic increase of fuel cost during the last few years has promoted interest in developing various energy saving methods and has revived the possibility of commercial sailing ships. In some countries feasibility studies regarding commercial sailing ships have already begun.

As Japan is a country with little natural resources, NKK is interested in the research and development of commercial sailing ships and began studying this subject last year sponsored by the Japan Marine Machinery Development Association.

The guiding principle of world-wide studies of sailing ships is to use sailing devices as main propulsion role, but considering the applicability to present-day commercial ships, it seems not practial. In this study, the development of Sail Equipped Motor Ships which use sailing devices as auxiliary propulsion role have been done aiming at more than 10% energy savings.

The basic data for development of sail equipped motor ships have already been collected through wind tunnel experiments and sea trials carried out in May, 1979, by our test ship "Daioh".

Although NKK is continuing research on sail equipped motor ships , we would like to present an interim - summary regarding our work so far.



2. Process of Research and Development

2-1. Goals for Development

The goals for the development of sail equipped motor ships have been chosen through investigation of a great many technical papers and data published world-wide regarding effective usage of wind energy.

The following were used as criteria;

(1) Applicable to existing commercial ships

(2) Large energy savings

(3) Special complements to be not necessary

(4) Little maintenance and repair work

Through this investigation, we have found that using wind energy directly as a propulsive force by sails is the most effective method for employing this natual power, however there will be many factors to consider in modernizing conventional sailing ships.

There are some essential points necessary for advancing the study of sail equipped motor ships which have been decided on in conjunction with the above criteria:

(1) Type of Ship

10,000 ~ 35,000 DWT bulk carrier

Ship speed: 15 knots

(2) Ship Propulsion Force

Sails to be used as auxiliary propulsion device aiming at more than 10% energy saving on the average.

(3) Sailing Device

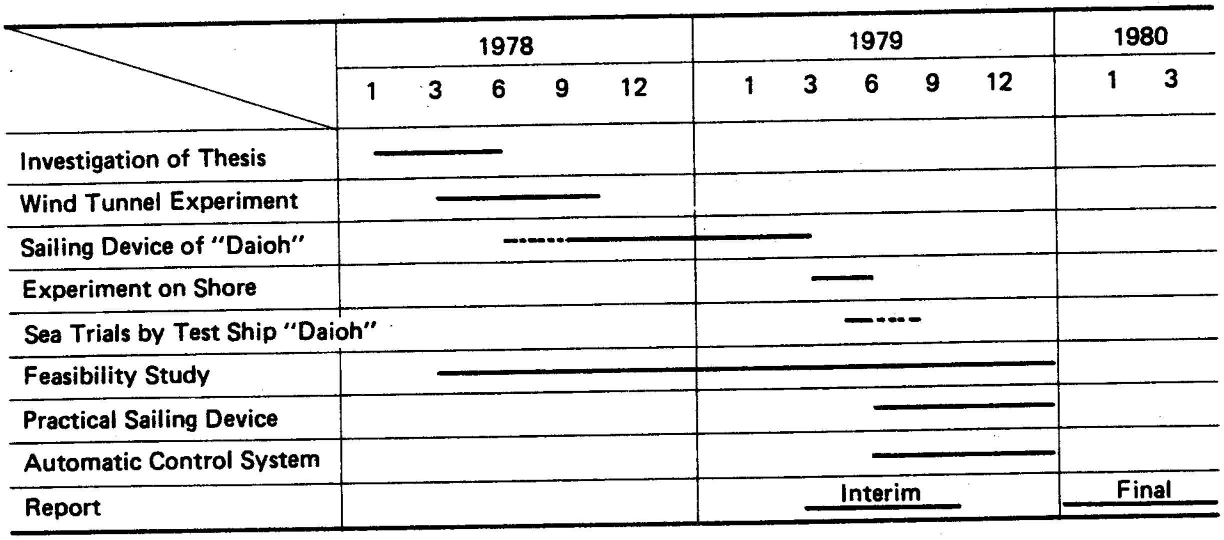
Sails to be automatically controlled making additional complements unnecessary.

Maintenance and repair work to be reduced as much as possible.

To the extent possible, sails should not be an obstruction for cargo loading and unloading.

2-2. Development Schedule

Development is going according to Table 1 and is to be accomplished over a period of 2 years.



3. Wind Tunnel Experiment

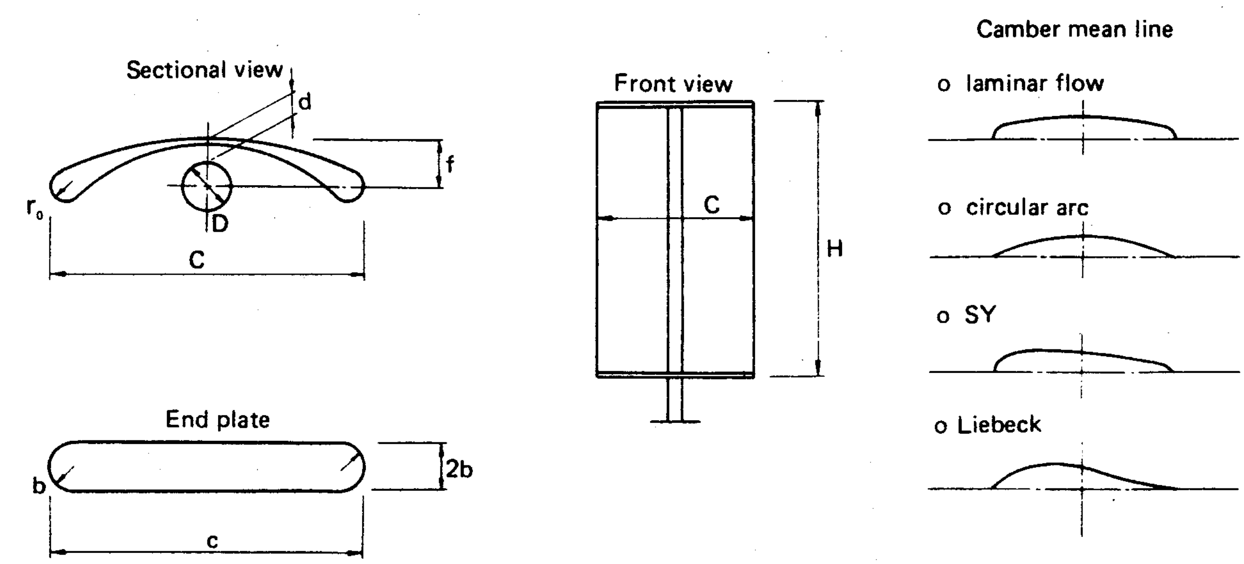
3-1. Experimental Parameters

Evaluating the outline performance of the sails through the investigation of technical papers, experimental parameters were determined as shown in Table 2 to perform a detailed test.

Table 2 Experimental Parameters

Sail Type	Camber: mean line	Camber: camber ratio	Leading-edge Radius (r_0/C)	Aspect Ratio (H/C)	Mast Location (d/D)	End Plate (2b/f)	Slot
Rigid Sail	L_1 : NACA a=1.0 (laminar flow type) L_2 : Circular arc L_3 : SY L_4 : Liebeck	F_1 =0.1 F_2 =0.12 F_3 =0.14	R_0 =0 R_1 =0.01 R_2 =0.02 R_3 =0.03	A_1 =2.0 A_2 =2.5 A_3 =3.0	M_1 =¼ M_2 =½ M_3 =1	E_0 =without E_1 =1.5 E_2 =3.5 E_3 =spindle shaped	S_0 =without S_1 : with
Soft Sail	L_1 L_2	F_2 F_3	R_0	A_1 A_2	M_2 M_3	E_0	S_0 S_1
Trianglar Sail (rigid & soft hybrid sail)	L_3				–	E_0	S_0

⟨Explanation of symbols & others⟩



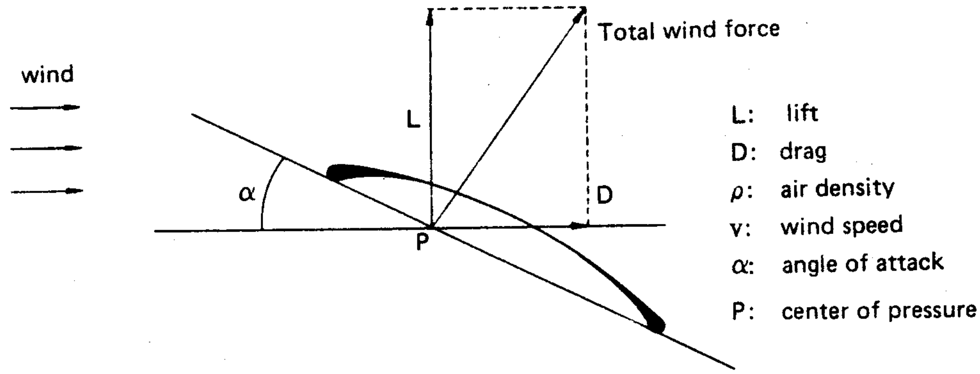
3-2. Results of Experiments

The most convenient forms for analyzing and presenting the data are the curves of lift coefficient versus drag coefficient. These are called Polar curves and give immediate visualization of the aerodynamic efficiency of sails.

– Lift and Drag Coefficient

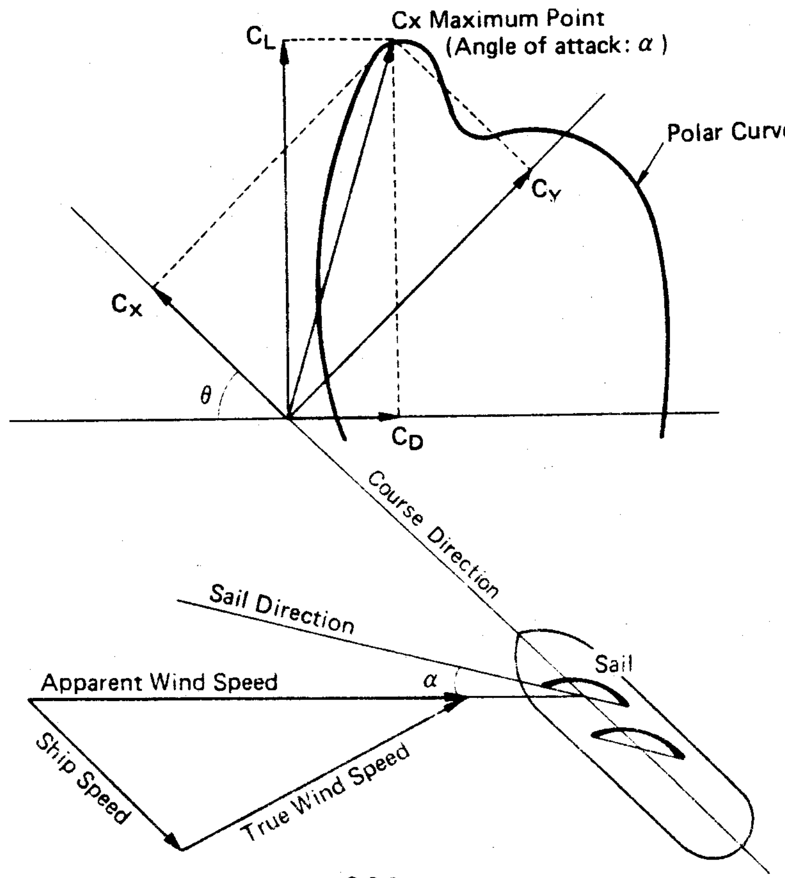
Lift and drag are obtained from wind tunnel test and expressed in terms of aerodynamic coefficients defind as:

$$C_L = \frac{L}{\frac{1}{2}\rho v^2 \cdot AS}, \quad C_D = \frac{D}{\frac{1}{2}\rho v^2 \cdot AS}$$



– Polar Curve

Lift and drag coefficient change with the angle of attack α, and the polar curve is obtained through experimentation by changing conditions a little each time.



– Driving and Side Force Coefficient

The total wind force can be divided into two components:

1) the driving force in the direction of ship's course and
2) the side force in the perpendicular direction.

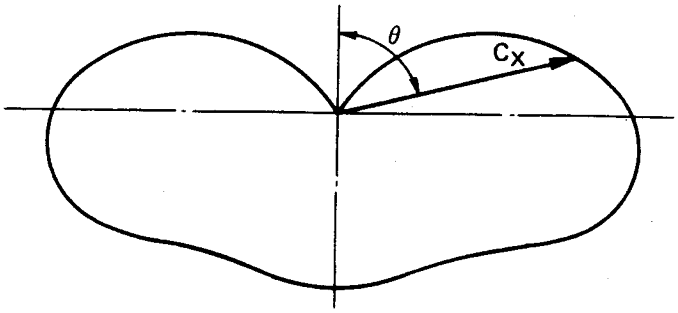
Coefficients of these forces C_X, C_Y respectively are related to C_L, C_D as follows:

$C_X = C_L \sin\theta - C_D \cos\theta$ (θ : course angle reffered to apparent wind direction)

$C_Y = C_L \cos\theta + C_D \sin\theta$

– $C_X - \theta$ Curve

This is the curve of the driving force coefficient C_X versus course angle θ, and is also a convenient form for analyzing the data.



1) Effect of Each Parameter on the Sail Performance

Detailed tests were performed changing the experimental parameters according to table 2 and visualized in polar curves. Observing those polar curves, particulary the C_L maximum-value, the effect of each parameter on the sail performance was evaluated as follows:

$L_1 > L_2 > L_3 > L_4$, $F_3 > F_2 > F_1$, $R_3 > R_2 > R_1$, $A_3 > A_2 > A_1$,
$M_3 > M_2 > M_1$, $E_3 > E_1 > E_3 > E_0$

2) Characteristics of the Sails Designed for the "Daioh"

Three types of sail devices were designed for the sea trials by the "Daioh". Model experiments at wind tunnel were performed and obtained the results shown in Fig. 1 and Fig. 2.

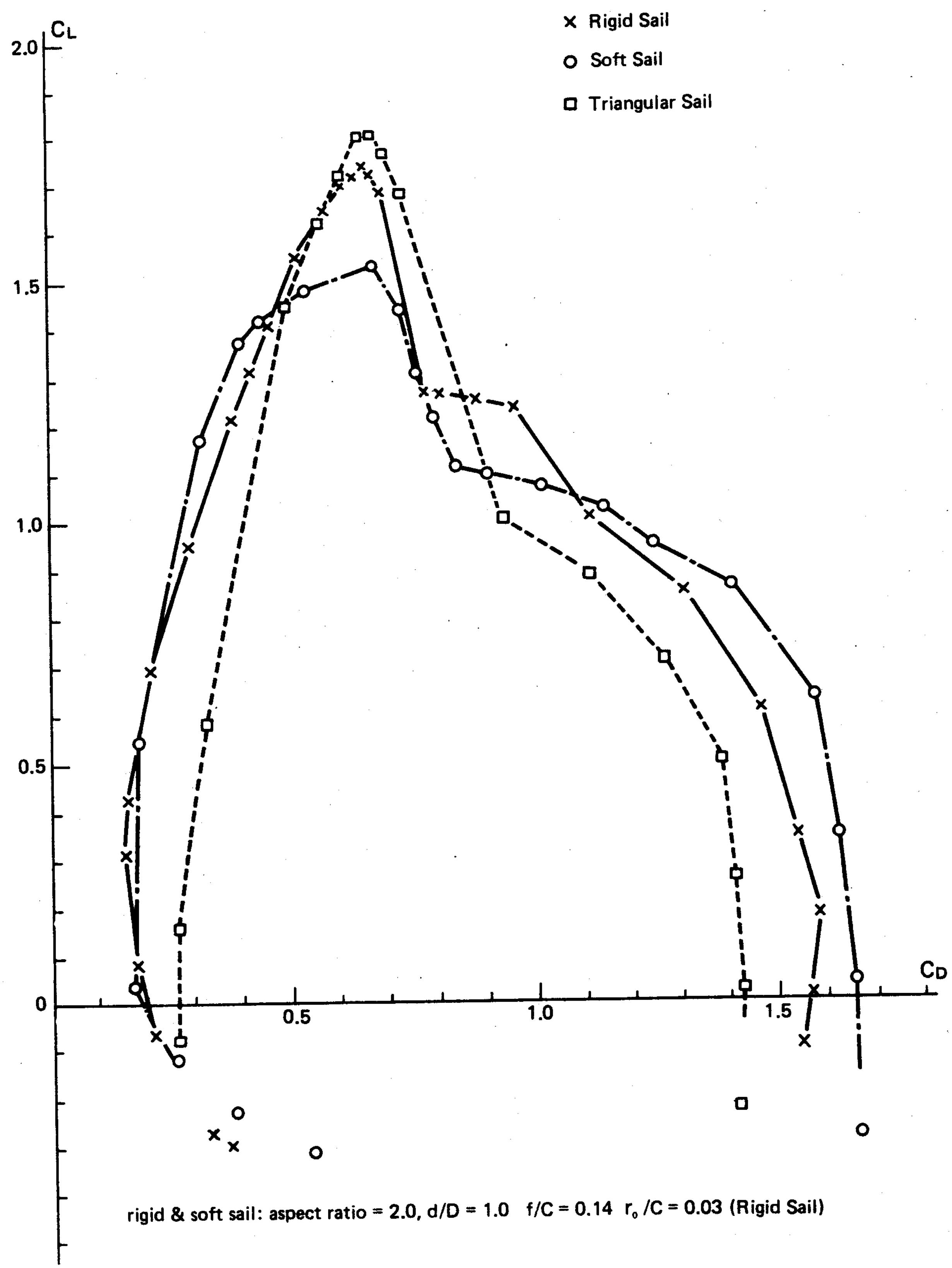


Fig. 1 Polar Curve of Each Sail designed for Daioh

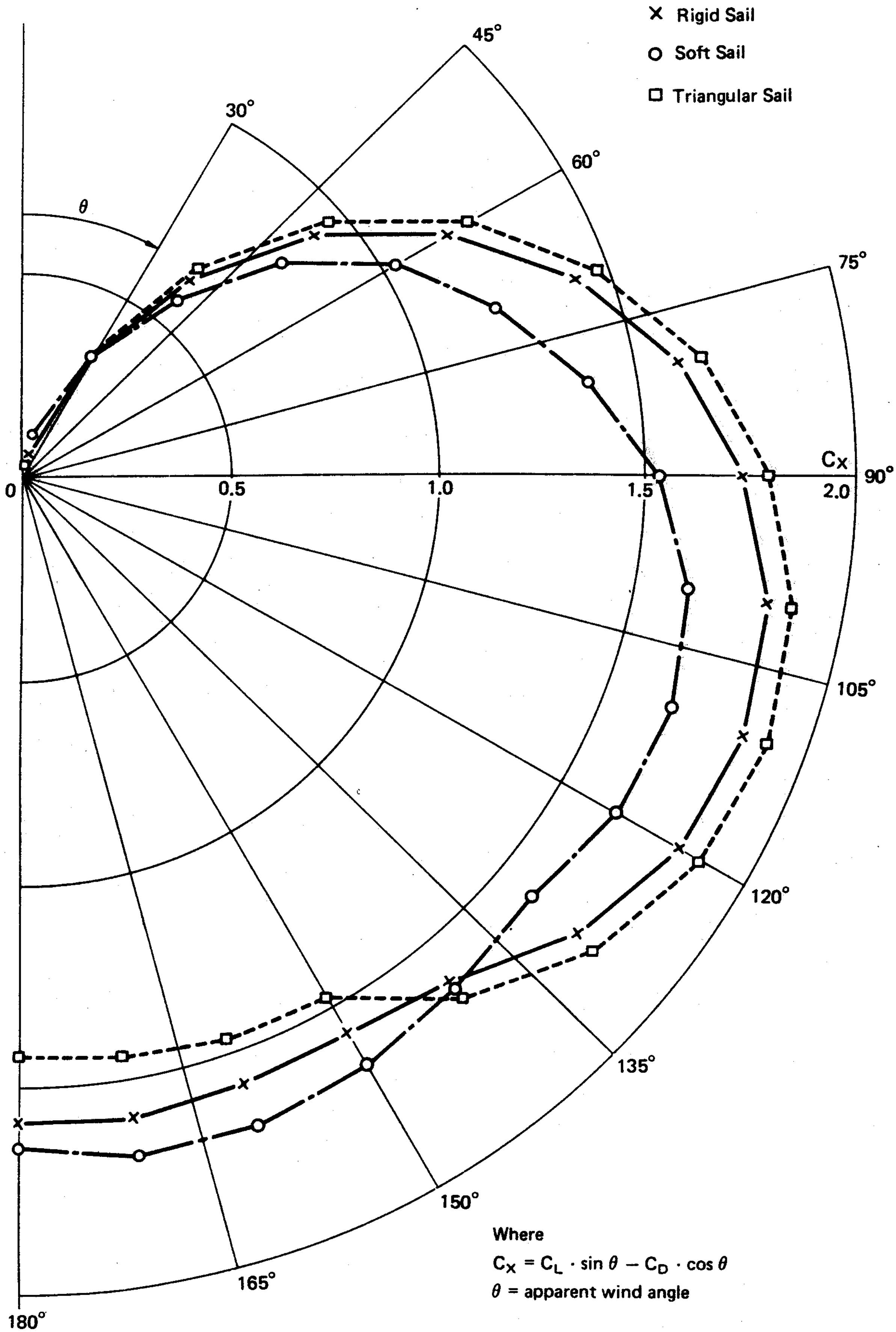


Fig. 2 $C_X - \theta$ Curve of Each Sail

4. Sea Trials by Test Ship "Daioh"

Large scale sea trials were carried out by our test ship "Daioh" to examine the following:

- To åssure the sail performance by a larger model
- Tó obtain the various sail effects on the ship at sea
- To demonstrate sails having mechanized trimming and sail stretching – folding devices.

4-1. Sailing Devices of "Daioh"

There are many requirements on modernized sails for motor ships, and it is difficult to design a sailing device satisfing all of them or to design an optimum sailing device.

Here, taking into consideration certain requirements on modernized sails, three kinds of sailing devices were produced by way sea trials in order to obtain the guiding principle for realization of sail equipped motor ships. The particulars are shown in Tàble 3 and 4.

Table 3 Sails for "Daioh"

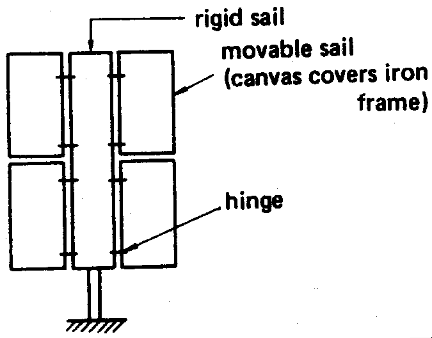
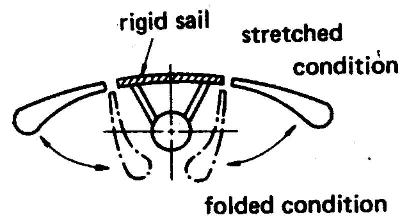
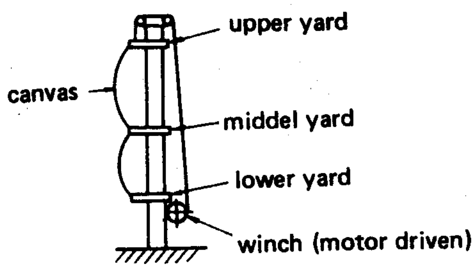
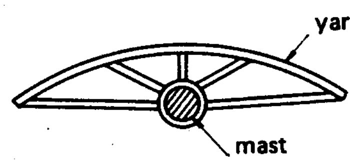
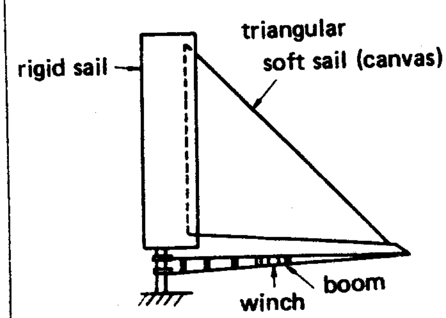
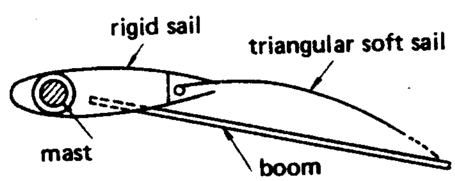
Sail Type	Front View	Sectional View
No. 1 Rigid Sail		
No. 2 Soft Sail		
No. 3 Triangular Sail		

Table 4 Sails Particulars for "Daioh"

Particular		Rigid Sail	Soft Sail	Triangular Sail: rigid part	Triangular Sail: soft part
Sail	Breadth (mm)	4,000	4,000	1,500	4,650
	Height (mm)	7,000	7,000	7,000	6,450
	Available Sail area (m^2)	28	28	10.5	13.9
	Camber mean line	laminar flow	laminar flow	laminar flow	–
	Leading-edge radius (r_0/C)	0.03	–	–	–
Sail Turning Device	Turn range (degree)	±100	±100	±100	–
	Turning speed (r.p.m.)	0.5	0.5	0.5	–
	Driving method	motor driven	motor driven	motor driven	winch
Sail Stretching & Folding Device	Stretching time (minute)	1	1	–	–
	Folding time (minute)	1	1	–	–
	Driving method	motor driven	motor driven		winch

4-2. Experiments on Shore

The performance of the rigid sail of the "Daioh" was tested to assure wind tunnel test results.

1) Results of Experiments

The test results on shore are shown in Fig. 3 which coincide fairly well with that of the wind tunnel. It affirmed that the test results in the wind tunnel are applicable to estimating the performance of sails when actually equipped onboard a ship.

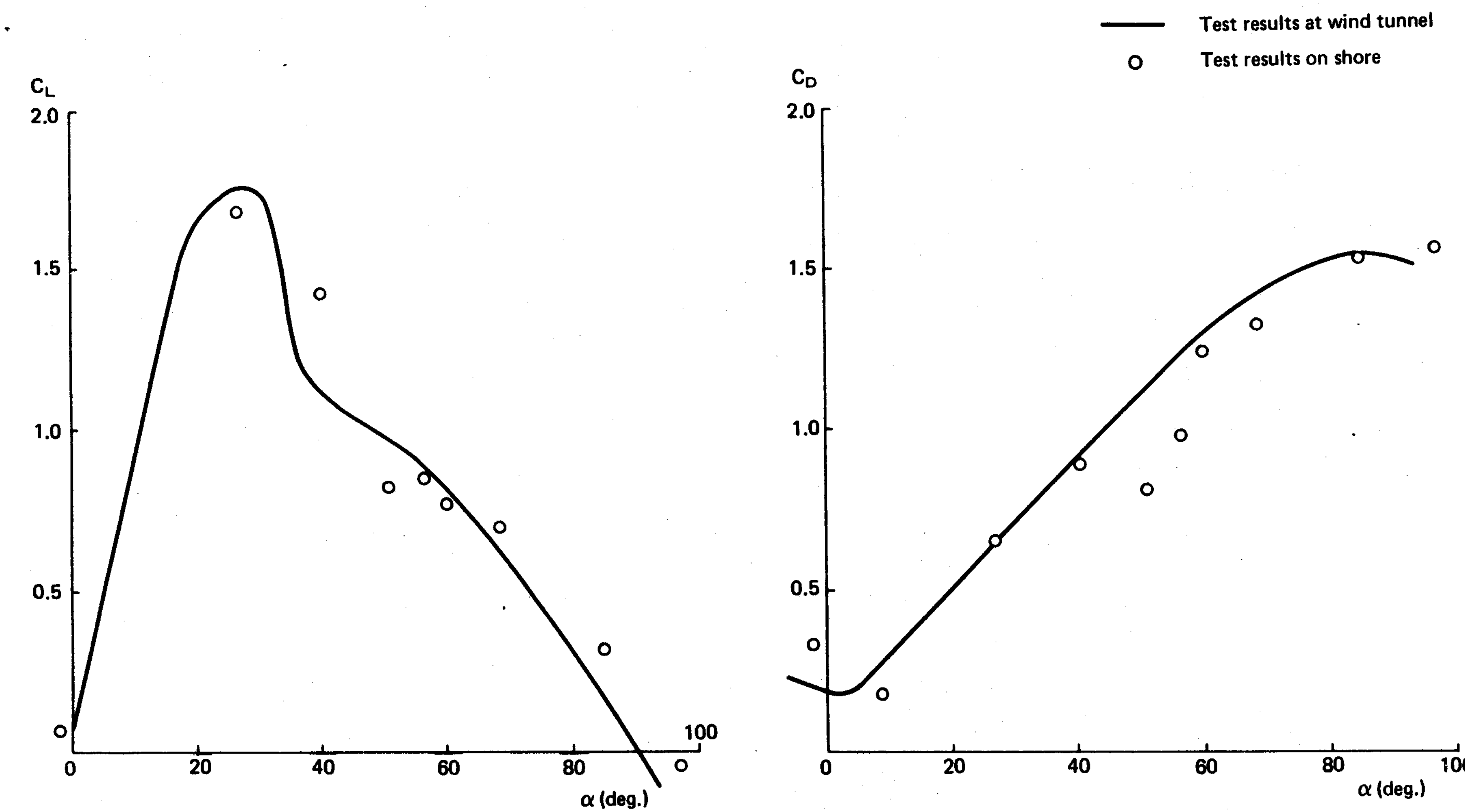


Fig. 3 Test Results of Rigid Sail on Shore

4-3. Sea Trials

1) Sail Arrangement

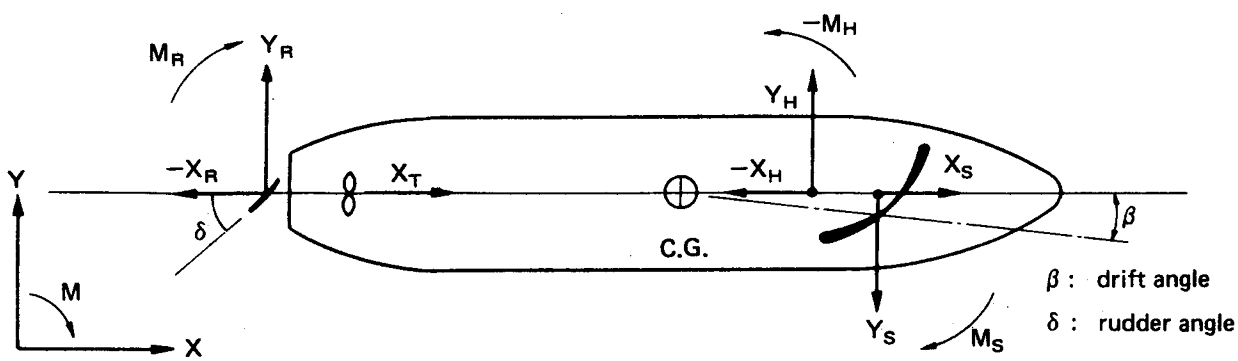
The balance of force and moment acting on the ship should be considered to determine the arrangement of the sails.

Balance of Force

propelling direction: $X_H + X_S + X_R + X_T = 0$

side force direction: $Y_H + Y_S + Y_R = 0$

Balance of Moment about C.G.: $M_H + M_S + M_R = 0$



where

Y_H : hydrodynamic side force on the ship hull

Y_S : aerodynamic side force on the sail

Y_R : rudder side force

X_H : hydrodynamic resistance on ship hull

X_S : aerodynamic propulsive force on the sail

X_R : rudder resistance

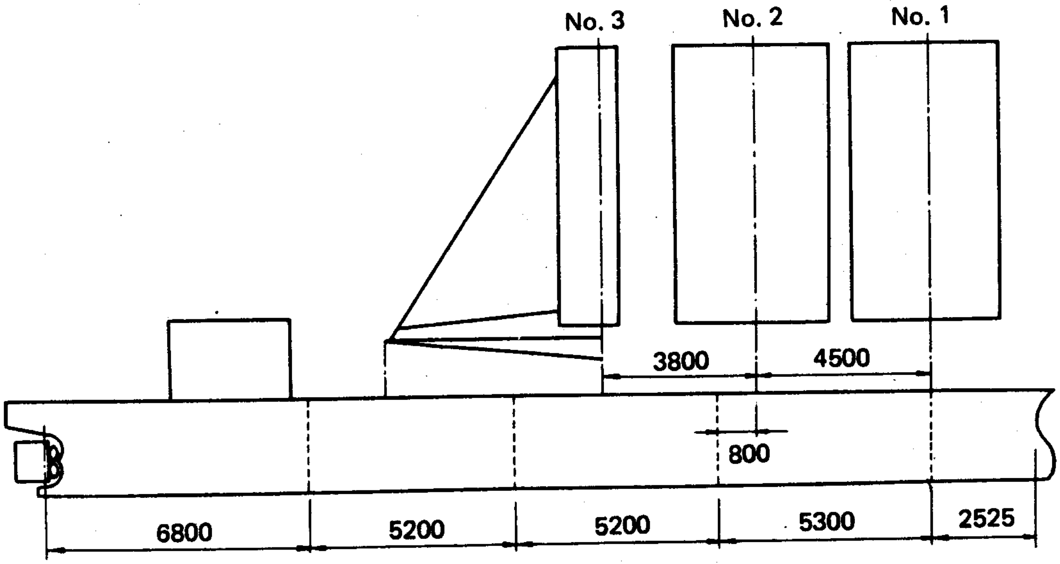
M_H : moment acting on the ship hull

M_S : Do

M_R : Do

X_T : $T(1-t)$ (T: propeller thrust, t: thrust deduction factor)

From these equations, the sail arrangement of "Daioh" was determined as follows:

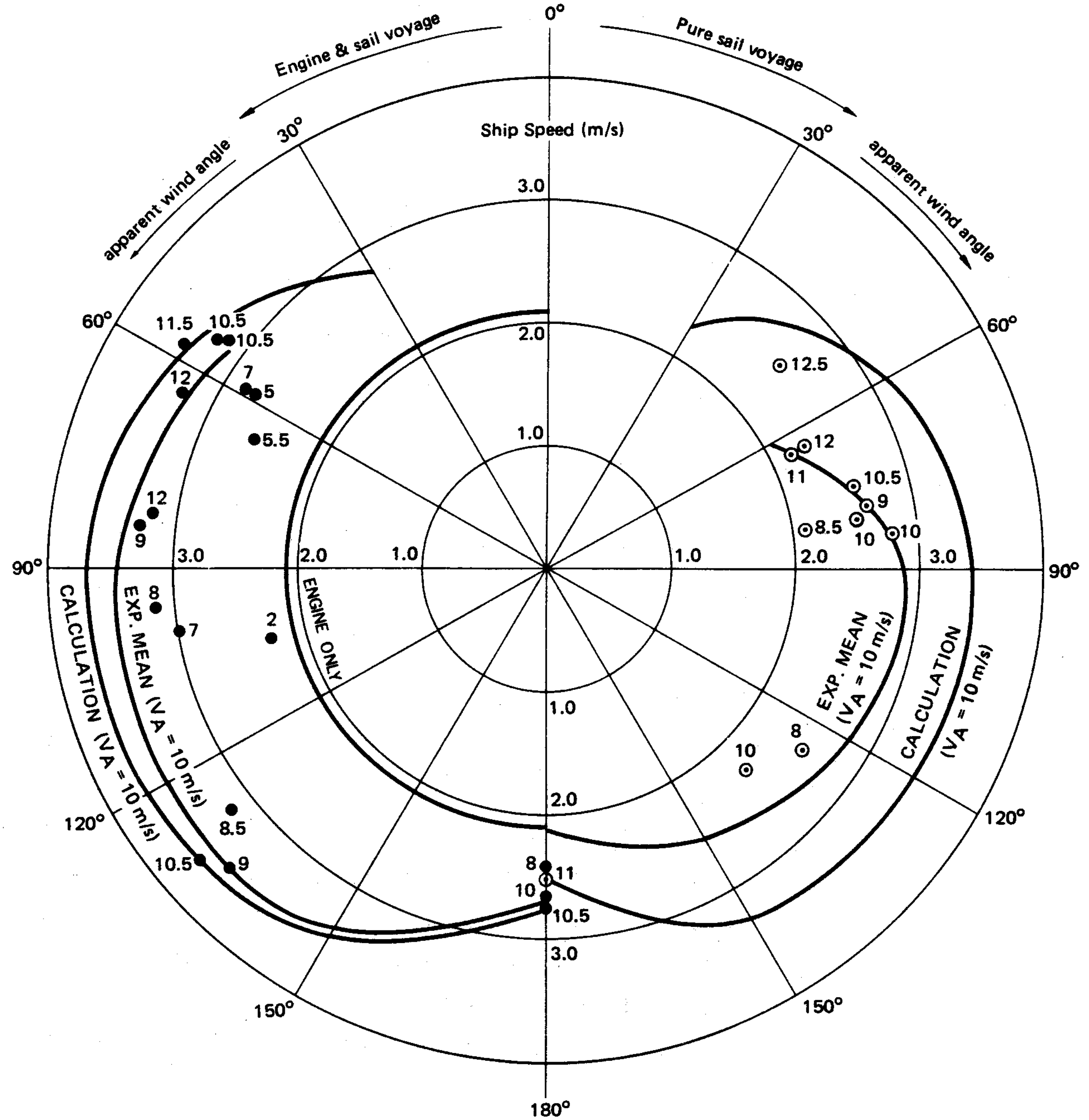


2) Results of the Sea Trials

Sea trials were performed from May to July in 1979. A full set of data was collected on propulsion by engine only, engine and sails and sails only.

The measured ship speeds are plotted in Fig. 4 and coincide fairly well with the estimated ship speed when it is propelled by engine and sails, while there is a little difference when it is propelled by the sails only. Taking into consideration many factors related to the ship speed, the measured ship speeds coincide well with the estimated value in the pure sails voyage too.

The course stability of the ship was satisfactory and proved that the sails were arranged correctly.



● w Engine & Sail Voyage (w : apparent wind speed m/s)

⊙ w Pure Sail Voyage (w : apparent wind speed m/s)

Fig. 4 Results of the Sea Trial

5. Feasibility Study

Feasibility studies on sail equipped motor ships have been done though there are still many problems left to solve, such as practical sailing devices and an automatic control system.

Research continues considering the following:

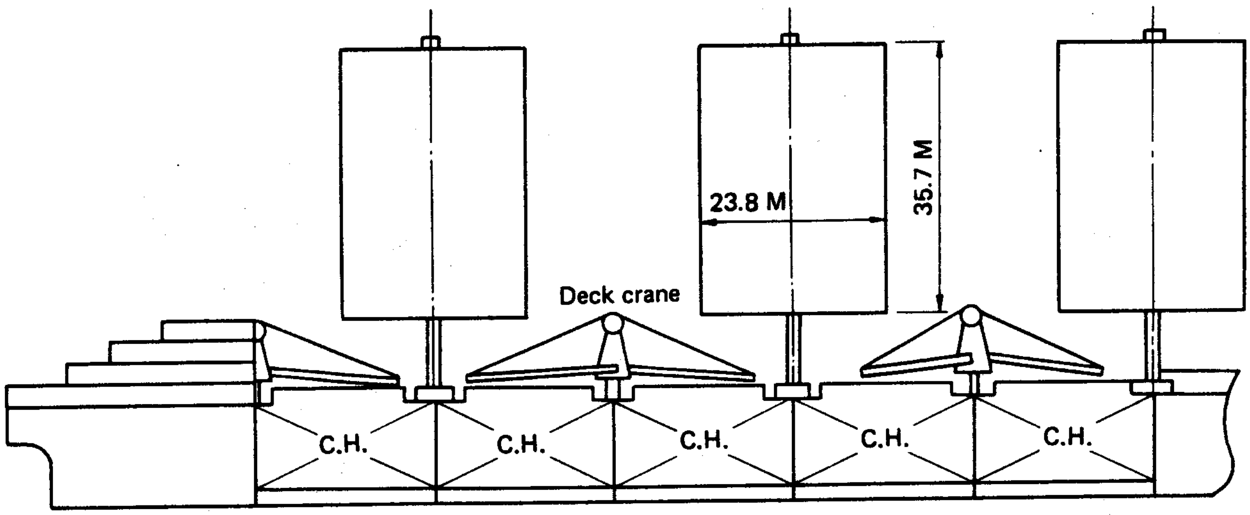
1) Ship and Sail Particulars

In order to investigate the effects of the ship size and its speed on the overall performance of the sails, the following is considered:

Bulk Carrier		10,000 D.W.T.	20,000 D.W.T.	35,000 D.W.T.
Sail Area		550 m^2 x 3 set	850 m^2 x 3 set	1200 m^2 x 3 set
Ship Speed (kts)	15	O	O	O
	12.5	–	O	–
	10	–	O	–

(Symbol O shows investigated cases.)

〈Example〉 In the 20,000 D.W.T. Ship



length (Lpp)	152 m	ship speed	15 Kts
breadth	23.8 m	main engine output (NSR)	7,480 PS
depth	13.0 m	rudder area	33 m^2
draft	9.5 m	sail area	2,550 m^2
displacement	26,400 t	sail area at folded	510 m^2

2) Route

A North Pacific route has been selected for reference due to it's commonness.

3) Overall Performance of the Sails at Sea

The wind speed and direction at sea change depending on the position, the season and the time of day. Thus the overall performance on a specific route should be calculated by considering not only the wind speed and its direction but also its frequency.

However, wind direction frequency is disregarded in the study and overall performance is calculated on the assumption that wind blows from all directions at the same frequency in order to be generally applicable to any other situations.

5-1. Results of the Feasibility Study

According to the feasibility study thus far, we can roughly conclude:

1) Effects of Ship Size and its Speed

It is proved that the effect of ship size on the sail power gain per sail area is negligibly small. Concerning the effect of ship speed, contrary to our expectation, more power gain per sail area is obtained when the ship speed is faster. We are investigating the optimum ship speed for sail equipped motor ships.

2) Power Gain and Loss

From the weather map of the North Pacific route, wind speed, direction and wind speed frequency were sampled and the overall performance of the sails was computed. Fig. 5 and Table 5 shows an example of the 20,000 DWT bulk carrier.

Table 5 Power Gain and Loss (Full Load Condition)

(20,000 DWT BC, Sail Area 850 m^2 x 3 set)

Sail	True Wind Speed (m/s)	Wind Speed Range (m/s)	Power Gain (Ps)	Power Loss (Ps)	Wind Speed Frequency (North Pacific)	Considering the Wind Speed Frequency		Net Power Gain (Gain – Loss) (Ps)
						Power Gain (Ps)	Power Loss (Ps)	
Streched (Fair Winds) or Folded (Contrary Winds)	5.0	3.75 ~ 6.25	270	140	0.227	61.3	31.8	29.5
	7.5	6.25 ~ 8.75	710	220	0.199	141.3	43.8	97.5
	10.0	8.75 ~ 11.25	1,600	280	0.156	249.6	43.7	205.9
	12.5	11.25 ~ 13.75	2,400	400	0.115	276.0	46.0	230.0
	15.0	13.75 ~ 16.25	3,270	620	0.075	245.3	46.5	198.8
	17.5	16.25 ~ 18.75	3,880	840	0.035	135.8	29.4	106.4
	20.0	18.75 ~ 20.00	4,290	1,070	0.006	25.7	6.4	19.3
Folded (Fair Winds Contrary Winds)	20.0	20.00 ~ 21.25	120	1,070	0.006	0.7	6.4	△ 5.7
	22.5	21.25 ~ 23.75	210	1,310	0.005	1.1	6.6	△ 5.5
	25.0	23.75 ~ 26.25	300	1,520	0.004	1.2	6.1	△ 4.9
						1138.0	266.7	871.3

Net Power Gain/Sail Area = 871.3 Ps/2,550 m^2 = 0.342 Ps/m^2
Net Power Gain/Main Engine Output = 871.3 Ps/7,480 Ps = 0.116

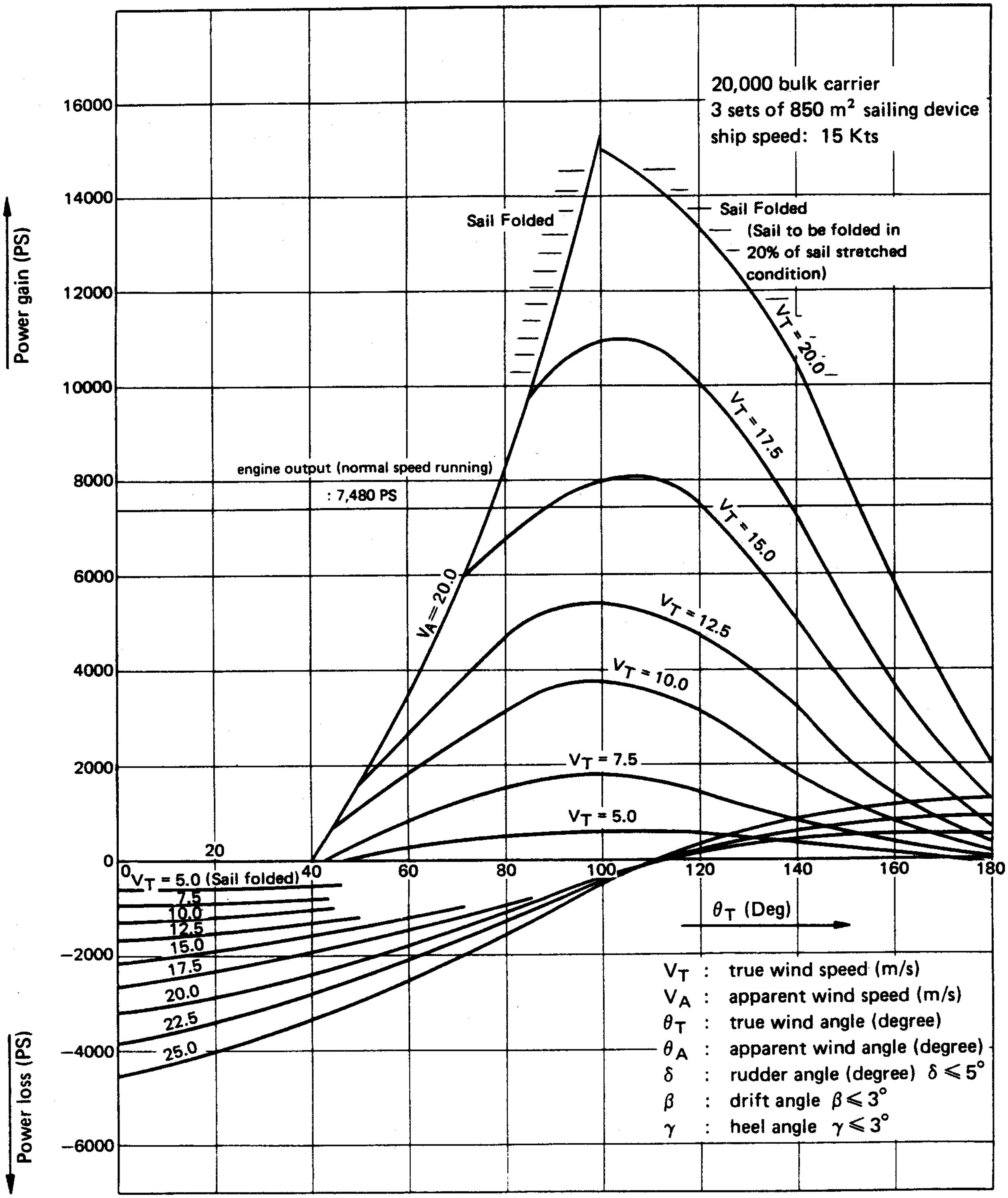


Fig. 5 Power saving curve (full load condition)

5-2. Economic Evaluation

According to Table 5, the overall power gain at full load condition is about 0.34 Ps/m^2, while at ballast condition it is about 0.26 Ps/m^2, and the overall power gain becomes about 0.30 Ps/m^2 on the average. This power gain corresponds to about a 0.3 ton/m^2 heavy fuel oil savings in a year.

There are some disadvantages in equipping the sails onboard a ship; the repayment of the initial investment, freight reduction because of the dead weight tonnage loss, running and maintenance costs, etc.

Evaluating these disadvantages economically and comparing this with the fuel oil savings, the total economic picture is roughly shown in the following example:

< Example in the case of a 20,000 DWT bulk carrier >

– Power Gain

		Full Load Condition	Ballast Condition	Average
Ship Speed	(Kts)	15	15.8	15.4
Power Gain	(Ps)	870	670	770
Power Gain/Sail Area	(Ps/m^2)	0.34	0.26	0.3
Power Gain/Main Engine Output		0.12	0.08	0.1

– Fuel Oil Savings

Fuel oil savings .... 830 TON/Y

- Power gain on the average: 770 PS
- 770 PS x 24 H/D x 300 D/Y x 150 x 10^{-6} TON/PS·H = 830 TON/Y

– Disadvantages

Freight reduction .... 5,600,000 YEN/Y

- Dead weight tonnage loss : △ 280T
  - Sailing device : △ 320T
  - Bunker (FO) : 40T
- 280 T x 10 Voyage/Y x 2,000 YEN/T. Voyage = 5,600,000 YEN/Y

Repayment and interest .... 25,500,000 YEN/Y

- Initial investment for sailing device: 170,000,000 YEN
- Repayment and interest: 15% of inicial investment
  170,000,000 YEN x 0.15 = 25,500,000 YEN/Y

Running cost and maintenance cost .... 5,000,000 YEN/Y

TOTAL Disadvantage 36,100,000 YEN/Y

– Total

Fuel Oil Price (YEN/TON)	Gain (YEN/YEAR)	Loss (YEN/YEAR)	Difference (YEN/YEAR)	Gain/Loss
20,000	16,600,000	36,100,000	△ 19,500,000	100 : 218
30,000	24,900,000	36,100,000	△ 11,200,000	100 : 145
40,000	33,200,000	36,100,000	△ 2,900,000	100 : 109

Judging from the above example, it does not seem feasible at present, however we can expect to realize sail equipped motor ships in the near future.

6. Conclusion

This report was prepared in the middle of our study and many problems still remain.

We have thus far performed experiments in wind tunnel, on shore and at sea. Through these experiments, various kinds of sail characteristics and the overall power gain of the sails equipped onboard a motor ship have been obtained. This is one of the most important results of this study.

A feasibility study is now under way and it is a bit premature to come to conclusions, but judging from rough calculations, we can expect the realization of sail equipped motor ships in the near future.

It will be an epoch-making event if we can accomplish fuel oil savings of more than 10% of commercial ships consumption, which amounts to as much as 140 million tons a year. We will continue our efforts to achieve this goal.

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FOR IMMEDIATE RELEASE:
NIPPON KOKAN K.K. (NKK)

May 9, 1983
(NKK NO. 83-13)

Sail-Equipped Cargo Carriers Completed and Launched

Japan's first commercial sail-equipped cargo carrier, the 699 gross ton "Senyo Maru" was delivered on April 21 to Fuyo Kaiun Kaisha Ltd., an NKK affiliated maritime transportation company, at Narasaki Shipyard in Muroran. This is the third NKK-designed sail-equipped ship. The initial two were tankers, including the world's first sail-equipped motor ship, the "Shin Aitoku Maru" and are already in service, an NKK spokesman said.

A sistership, the "Nissan Maru," owned by Nissan Senpaku Ltd. was launched on April 15 at Sasaki Shipyard in Hiroshima and is scheduled to be delivered at the end of May.

The research and development of sail-equipped motor ships has been carried out by NKK in cooperation with the Japan Ship's Machinery Development Association, which resulted in the commissioning of the world's first sail-equipped tanker, the "Shin Aitoku Maru" featuring micro-computer control system for sail operation.

Both sail-equipped cargo carriers will sail in Japanese coastal areas. The "Senyo Maru" will be mainly used to carry steel products for NKK from the Keihin Works and the Fukuyama Works to other Japanese ports, while the "Nissan Maru" will transport mainly raw materials.

Both ships are equipped with two sets of rigid square sails, made up of steel frame and poly-coated canvas, the fore installed on the bow and the aft installed over the bridge. A micro-computer will control the sail function so no additional crew is required for operation of the sails.

Another feature of the sailed carriers is the implementation of a ship speed control system by a micro-computer which controls the revolution of the main engine together with the controllable pitch propeller to achieve the minimum fuel consumption while maintaining a preset ship speed.

The main engine is designed to allow use of low grade oil of RW No.1 3,500 sec. $100^{o}F$ as fuel which has not been utilized for this type of engine previously, thus economizing fuel consumption and energy saving.

The main particulars of the new ships are as follows:

Gross tonnage:	699 tons	
Deadweight tonnage:	2,081 MT	
Dimensions:	Length overall	76.5m
	Length bp	72.0m
	Breadth molded	12.6m
	Depth molded	6.9m
	Draft	4.72m
Main engine:	NKK-SEMT Pielstick 6PA6L	
Sails:	No.1 14.5m x 9.5m:	$138m^2$
	No.2 12.0m x 8.0m:	$96m^2$
Total sail area:	$234m^2$	
Service speed:	11.0 knots	
Class:	NK, coastal	

VOLUME I

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